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MORAINES OF RECESSION AND THEIR SIGNIFICANCE IN GLACIAL THEORY.[1]

CONTENTS.

Introduction.
Value of the Cincinnati-Mackinac moraine series as a basis of interpretation.
Known periodic oscillations of climate.
Theoretical effect of precessional oscillations of climate upon the ice-sheet
Character of the glacial oscillations as revealed by the drift.
Probable rate of ice-sheet motion.
Englacial transportation and deposition.
Probable duration of the periods of glacial oscillation.
Superposition of the oscillation upon a greater and much longer climatic variation.
Summary.

INTRODUCTION.

The principal facts which form the basis of this paper were presented in an article read before the joint session of the Geological Society of America and Section E of the American Association for the Advancement of Science at Buffalo in August 1896.[2] They may be briefly summarized as follows:

During parts of the seasons of 1893, 1895 and 1896 the writer explored the eastern coast of Michigan southward from Mack-

[1] An abstract of this paper was read before the Geological Society of America at Washington, December 31, 1896.

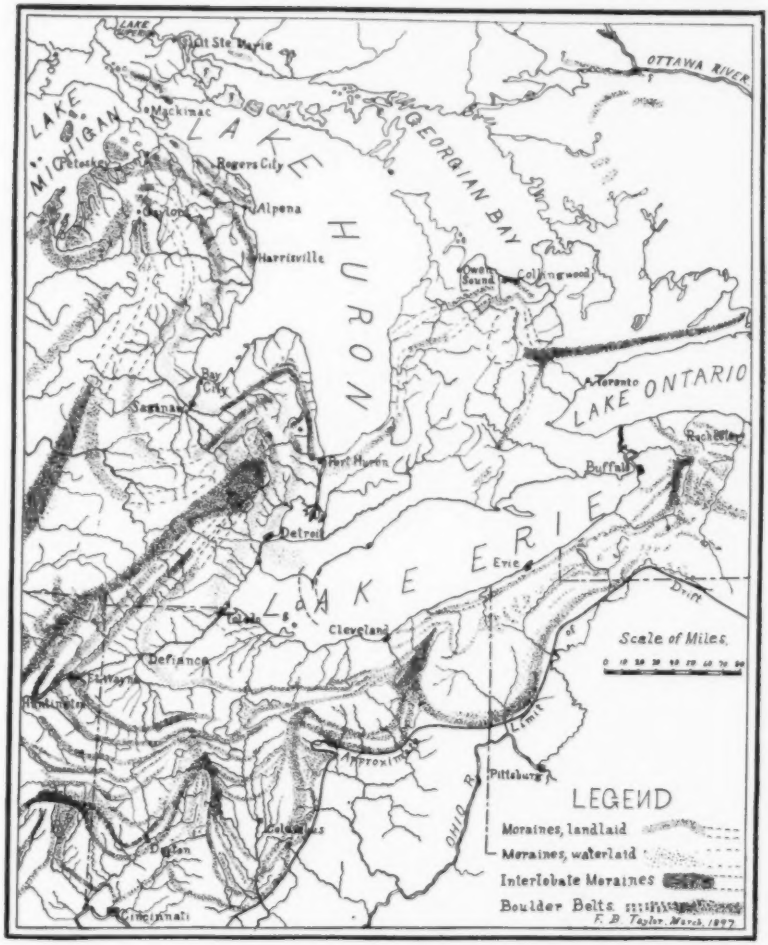
[2] "Glacial Succession in Eastern Michigan." Abstract in Am. Geol. for October 1896, p. 234.

inac straits chiefly with the object of tracing the old shore lines. Incidentally, however, much information was gathered concerning the terminal moraines which lie in the same area. Their development and relations were found to be for the most part very simple. Between Mackinac straits and Toledo, Ohio, five moraines were found arranged in consecutive order or in series, and the series is regarded as complete within this interval. The work of the past season brought the moraines of Michigan into connection with those of Ohio and Indiana where their relations had been worked out by earlier observers — by G. K. Gilbert and N. H. Winchell in northwestern Ohio, by C. R. Dryer in northeastern Indiana, and by F. Leverett in western and southwestern Ohio.[1]

According to Mr. Leverett and Professor Chamberlin the drift of the Wisconsin glacial epoch extends down into southwestern Ohio nearly to Cincinnati.[2] Near this place its farthest limit is marked by a terminal moraine, and from this there is a series of moraines extending northward to the Maumee valley. Numbering the moraines up from the south the one that passes through Defiance is the tenth. By the work of the several observers mentioned, the whole interval from Cincinnati to the Straits of Mackinac has been explored, and the sum of the terminal moraines in the whole series is fifteen. And further, not

[1] GILBERT in the reports of the Geological Survey of Ohio, Vol. I, 1871, chap. xxi, p. 357. WINCHELL in Proc. A. A. A. S., Vol. XXI, 1872, pp. 171–179; Geological Survey of Ohio, Vol. II, 1874, pp. 56, 431–433. DRYER in the 16th, 17th and 18th reports of the State Geologist of Indiana, 1888 to 1894. LEVERETT in Am. Jour. Sci., Vol. XLIII, 1892, pp. 281–297; JOUR. GEOL., Vol. I, No. 2, 1893, pp. 129–146.

[2] MR. LEVERETT speaks of this as "the later drift." (JOUR. GEOL., Vol. I, No. 2, p. 138.) PROFESSOR CHAMBERLIN afterwards applied the name "East-Wisconsin formation" to this drift, and the same is now known as the "Wisconsin formation." (GEIKIE'S "Great Ice Age," 1894, p. 763 and map opposite p. 727. Also in JOUR. GEOL., Vol. III, No. 3, pp. 270 and 275.) PROFESSOR CHAMBERLIN recognizes, with a reservation of doubt, a division of the moraines of the Wisconsin formation into "earlier" and "later" groups. ("Great Ice Age," pp. 763–764.) But this division would make very little difference in the conclusions reached here. For in the Miami valley the first moraine north of Cincinnati is the only one belonging to the earlier group. All the rest of the series northward to Mackinac belong to the later group and are therefore a consecutive series in time.



Map showing Moraines of Recession between Cincinnati and Mackinac.

only is it ascertained that there are fifteen moraines between Cincinnati and Mackinac, but the conditions of glacial motion and drift deposition were so simple along the entire line that it is substantially certain that the series is full and complete. Three more moraines in the same series, but possibly not consecutive, were found north of the straits. In making the count the central axes of a connected series of wide open valleys was followed—up the Miami valley, down the Maumee, up the Detroit and St. Clair and thence northward along the west shore of Lake Huron. This course was chosen because the ice motion was naturally the freest in the open valleys where the resistance was least, and the oscillations of the ice-front were recorded there more distinctly than anywhere else. This line avoids all interlobate and other morainic complexes and follows the valley axes where the amplitude of the peripheral oscillations of the ice-sheet was naturally greatest.

On examining the configuration of the individual moraines and on comparing the intervals of distance between them (shown on the accompanying map) it is apparent that the principal irregularities of the moraine series are due to topographic influences. As the ice-sheet crept along it moved forward farthest and fastest in low wide valleys like the St. Clair-Detroit valley, and it lagged behind on the hills and highlands as on Blue Mountain south of Georgian Bay, on the highlands south of the Straits of Mackinac, and on the "thumb" between Saginaw Bay and the south arm of Lake Huron. The relative width of the valley and the relative height of the bounding highlands had a considerable effect upon the amplitude of the oscillations at any given point. For in a narrow valley, between relatively high side lands, as was probably the case to a slight extent in the Miami and Sciota valleys, the ice movement was cramped and the amplitude of oscillation more or less reduced. The ice-lobes that spread away southward from the Huron, Saginaw and Erie lake basins were wonderfully sensitive to topography. Differences of level of the general land surface over which they moved amounting to as little as a hundred or even fifty feet determined

the direction of flow and shaped the lobes. The intervals between the moraines show some irregularity, but on a close study of the relief of the region, with due allowance for its influence upon the ice-motion, it seems clear that if the uneven features of the land surface had been wholly absent the moraine series would have been perfectly regular, either with equal intervals or intervals showing a regular order of variation.

VALUE OF THE CINCINNATI-MACKINAC MORAINE SERIES AS A BASIS OF INTERPRETATION.

So far as known to the writer there is no other glaciated area of like extent where a moraine series is found so simple and complete as that between Cincinnati and Mackinac. Similar moraine series are known in many other places — most notably in the adjacent areas of the Sciota Valley in Ohio, in southwestern Michigan and northwestern Indiana, and in Illinois, Iowa, Minnesota and the Dakotas, but in none of these regions are the phenomena of equal simplicity or completeness. A few moraines in series are known in the eastern states and New England, and a few also in Europe, but in all these regions they fall far short in comparison. The series of moraines extending northeastward from Defiance to Rochester, N. Y., may ultimately prove to be as good as that extending to Mackinac, but at the present time it appears to be incomplete. Eastward from Cleveland especially the lower moraines are closely packed on the steep northward slope. In the Dakota-Minnesota series Mr. Upham finds twelve moraines,[1] but it is perhaps somewhat doubtful, as was recently pointed out by Professor Todd, whether all these moraines are in one series.[2] In Illinois, western Indiana and southwestern Michigan, Mr. Leverett finds a number of moraines in series, but there are overlaps in the area, and in Illinois, especially, the individuals join and separate so often, form-

[1] "The Glacial Lake Agassiz," by WARREN UPHAM; Monograph XXV, U. S. Geological Survey, 1896, pp. 139–141. Also, Twenty-second Ann. Rept. Minn. Geol. Survey, Part III, 1894, p. 45.

[2] "A Revision of the Moraines of Minnesota," by J. E. TODD. Abstract in Am. Geol. for October, 1896, p. 225.

ing a series of complex loops, that the system appears at present confused and a complete and simple series is not easily made out. The moraines of the Saginaw lobe in all probability make a simple series of at least eight or ten members, but they have not yet been fully explored. The chief element of confusion in these several areas appears to be due mainly to the influence of a relatively complex topography. There may have been other causes of complexity, but the land relief is clearly the most important.

The individual moraines of the Cincinnati-Mackinac series are also as a rule simpler in their reliefs, in the curves by which they cross the valleys, and the intervals between them are wider and more regular. Their relations to each other and to the adjacent higher lands are also simpler.

On account of their completeness and simplicity, therefore, the moraines of the Cincinnati-Mackinac series constitute the best body of facts now known for the study of the cause of the oscillations of the retreating ice-sheet, and there appears to be little prospect of ever finding a better one. With few exceptions a comparison of other moraine series shows at once that the reason the Cincinnati-Mackinac series is so simple is that the land relief which the ice encountered along this line was of the simplest sort. Such a comparison in nearly every instance strengthens the conclusion that if the ice-sheet had moved over a perfectly plane surface the moraines would have been laid down at regular intervals or else at intervals varying progressively in a regular way. In short, the departure from perfect simplicity and regularity in the moraine series of any ice-lobe seems to be in a general way proportional to the magnitude, number, and complexity of arrangement of the larger topographic features which it encounters.

KNOWN PERIODIC OSCILLATIONS OF CLIMATE.

It has been supposed by many, and apparently with good reason, that northern lands were elevated to relatively high altitudes during the Ice age. This is held by some to have been

the chief causal condition. But whatever the cause of the Ice age itself may have been, it seems hardly possible to account for the moraines of recession by any scheme of ups and downs of the solid earth. The moraines themselves indicate that the oscillations of the ice-front were of a periodic nature, and therefore dependent upon the operation of a periodic cause. All geological forces that are purely terrestrial are necessarily derived from the interior of the earth, and there is no evidence that their activities are periodic, although they may recur at irregular intervals. Still less is it possible to conceive of true periodicity in the surface manifestations of purely terrestrial forces, such, for instance, as would be required to explain periodic movements of elevation and subsidence over wide areas, especially where the amount of the successive movements would have to be regulated to the extreme nicety of progressive variation requisite to produce the climatic cause of the moraines of recession. All such supposable terrestrial causes may therefore be safely put aside.

To find a source for periodic causes we are compelled to turn to astronomy. According to established doctrines the only way in which astronomical forces can be supposed to influence glaciation is through climate. The annual period of climatic change is so short that it is, of course, out of the question. A period of climatic change in rounds of about thirty-five years has been deduced by Forel and others from the study of the variations of glaciers and of rainfall.[1] But, as will be shown farther on, this too seems far too short. After this the only known period of climatic variation is that due to the precession of the equinoxes,

[1] F.-A. FOREL. (Archives. Sci. Phys. Nat., May 15, 1886, p. 503.) Forel points out that the variations of rainfall and air temperature, as deduced by C. Lang, agree with his own periods of variation in Alpine glaciers. (Also Am. Jour. Sci., for July 1886, p. 77.) In Forel's latest writing on this subject ("Les Variations Periodiques des Glaciers," Genève, 1895) he finds the grounds for deducing a definite period to be rather unsatisfactory. He finds that glaciers of different sizes and lengths do not show the effects of causes of advance or retreat synchronously. After a few seasons of increased precipitation all glaciers tend to advance, but small ones advance sooner than great ones so that they do not attain their maxima at the same time. A small glacier will reach its maximum and get far back on its retreat before a greater glacier attains its maximum advance — a result that is natural from the fact that the effects

and the movement of the perihelion of the earth's orbit. Mr. G. K. Gilbert has used this period of climatic oscillation in connection with another matter. His statement relating to the length and variability of the precessional period is concise and convenient. "The precessional period is about 26,000 years, but the position of the perihelion also moves—for the most part in a direction opposite to that of the equinoxes—and the resultant of the two motions has an average period of about 21,000 years. It is not absolutely regular, but ranges ordinarily within 10 per cent. of its mean value, and exceptionally to 50 per cent. above and below."[1] The period at 21,000 years seems too long, but if we take it at its minimum of 10,500 years, it may not be.[2]

THE THEORETICAL EFFECT OF PRECESSIONAL OSCILLATIONS OF CLIMATE UPON THE ICE-SHEET.

Let us see in what manner the astronomical forces would work, supposing the oscillation of the ice-front to be due to precession. Precession is produced by the rotation of the axis or pole of the earth around the pole of the ecliptic. The figure thus described on the celestial sphere is not in reality a true circle, but for the purposes of this paper it may be assumed that it is, without in any way impairing the general truth or validity of the conclusions reached. The general idea of the influence of precession upon terrestrial climate has been so often discussed that it is hardly necessary to dwell at length upon it here. But it is

of causes of advance or retreat proceed in waves downward from the névé to the end of the ice-tongue. From this and other causes of complication he finds it hard to make out clearly any regular period of variation. Nevertheless, it is probable that a thirty-five-year period exists. The progress of investigation along this line is well summarized by Professor H. F. Reid, "Variations of Glaciers," JOUR. GEOL., Vol. III, No. 3, 1895, p. 278 et seq.

[1] "Sedimentary Measurement of Cretaceous Time," by G. K. GILBERT. JOUR. GEOL., Vol. III, No. 2, 1895, pp. 121–127.

[2] There is a possibility that the period of precession during the glacial epoch was considerably shorter than the minimum of the modern calculation. Perhaps the chance of this seems very remote, but there are small changes going on, now apparently secular, which in so great a lapse of time may prove to be periodic and may come to be of prime importance in their effects on terrestrial climate.

necessary to see clearly how the position or place of the ice-front is related to this kind of climatic change. The change of climate from this cause does not go on with the rotation of the earth's pole *pari passu*. For the pole, under the simplified conditions here postulated, moves in a circle and changes its position at a uniform rate. The effect of this movement on climate is to produce a periodic or oscillatory change to and fro between two extremes or climaxes, and these changes go on in an endless alternating series, from cold to warm, from warm to cold, from cold to warm, and so on. In glacial times a climatic variation of this sort, even if it were slight in amount, must have had its effect on the ice-sheet. As climate grew more severe the ice-sheet would advance its front all along and spread over a larger area, and as climate moderated the ice-front would draw back and the area of the ice-sheet would be reduced. Thus it may be demonstrated that the effect of a precessional oscillation of climate upon the ice-sheet would be to cause it to alternately increase and decrease its area by a series of expansions and contractions, and this process would necessarily be accompanied by a corresponding series of alternate advances and retreats of the ice-front. We are thus enabled to infer the character or manner of the oscillations of the ice-front, supposing them to be due to precession. They would obviously follow the manner of what is called simple harmonic motion. If a wheel be made to rotate on a fixed vertical axis a point or peg on its rim describes a circle when viewed from above. But if we look at the wheel edgewise, or from the side, the peg appears to move to and fro along a straight line, more slowly near the ends, fastest in the middle, and coming to rest for an instant at each extremity. The manner of the apparent motion is like the swinging of a pendulum viewed from below. This is the manner in which the forward and backward movements of the ice-front would take place if produced by precession. As the cold increased after a warm climax, the ice-front would advance, at first slowly, but at increasing rate, until the middle point of the oscillation was reached; then more and more slowly until it came to rest at its cold or

forward climax, where it would halt and build a terminal moraine. Then as climate ameliorated the ice-front would retreat in the same fashion and at its warm or backward climax it would again halt and build a moraine. The moraines of the cold climaxes would always be built after an advance movement, and would therefore be left standing. But the moraines of the warm climaxes would always be built after retreats and just before advances, and would therefore be overridden and destroyed. From these considerations it is plain that the time during which the ice-front would stand at or near its extreme forward position while building its terminal moraine at the cold climax would be only a fraction of the whole precessional period. The precise value of this fraction depends upon three factors: (1) on the period or duration of the precessional oscillation of climate; (2) on the amplitude of the oscillation of the ice-front, and (3) on the width of the drift belt which takes the form of a terminal moraine at the cold climax. The character of the moraine built would vary considerably according to the manner of combination of long or short periods with small or great amplitudes. Other factors, such as the quality and quantity of the drift, the land relief, the situation with reference to the margin of the lobe (frontal or interlobate), latitude and local climatic influences modify the character of the moraines more or less, but need not be discussed further here.

By way of illustration let us consider a hypothetical case Suppose the amplitude of oscillation to be thirty miles, which is probably not far wrong for certain localities, and the period to be 10,000 years, which is in round numbers the supposed minimum value of the precessional period. The moraines are from two to ten miles wide, the average being not far from five. Their width varies considerably in different regions and different situations, but the figures given are approximately true for northwestern Ohio, northeastern Indiana, and southeastern Michigan

Figure 1 represents a simple harmonic motion in which *A B C D* is the circle of reference and represents the circle which the pole of the earth describes on the celestial sphere in 10,000

years. The diameter *A C* may be taken to represent the amplitude of the oscillation of the ice-front as affected by the precessional oscillation of climate, and is put at thirty miles. Of course the ice keeps melting as it moves forward so that there is no material thing that constantly accompanies the ice-front as it changes its position. But we may imagine a point which shall keep its place constantly at the front edge. This point would move to

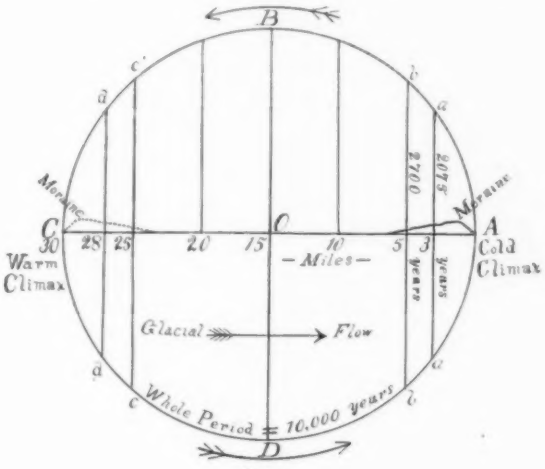


FIG. 1.

and fro with the ice-front on the line *A C*, following the order of the precessional changes of climate. An arrow within the circle shows the direction of the general glacial flow, which is maintained in the glacier itself through all phases of advance and retreat of the ice-front. The climaxes of cold will therefore be at *A* and the climaxes of warmth at *C*, and the ice-front will have a period of rest at each of these points. When the ice-front passes *O* it will always be moving at the maximum rate, whether of advance or retreat. As the ice-front moved forward from *O* to *A* its rate of advance would decrease, and would become very slow on approaching near to *A*, and the retreat

from *A* to *O* would have the same character in reverse order. The five miles nearest to *A* represents the approximate width of the belt in which terminal moraines at the cold climaxes are built. If the whole period of precession be 10,000 years and the amplitude thirty miles, it is easy to show that the ice-front would be within the five-mile belt (*bb'*) about 2700 years, and within the three-mile belt (*aa'*) about 2075 years. A period of terminal moraine building of the same duration would also take place at *C*, the warm end of the oscillation, but the moraines built there would always be overrun and destroyed at the next advance.

If this process were carried on with ideal simplicity the resulting forms of the terminal moraines at the two extremes of oscillation would be substantially as represented in cross section in the figure. Those at *A* would have relatively short, steep front slopes and long, gentle back slopes, while those at *C* would have long, gentle front slopes and short, steep back slopes. In the moraine series as we have it, all those made at *C* have been destroyed, and we have left only those made at *A*. We shall see presently that where the conditions were simplest the moraines do in fact show plainly a tendency to take the form shown at *A*.

If the period of precession were 20,000 years, the amplitude remaining the same, the time of the ice-front in the five-mile belt would be doubled, or 5400 years. On the other hand, if the period were 5000 years the time in the five-mile moraine belt would be 1350 years, and in the three-mile belt 1037 years.

The character of the moraine would also be affected by the amplitude of the oscillation, the period remaining the same. The amplitude would necessarily vary greatly in different places, the chief determining condition being the character of the land relief and the relation of the ice to it. Against a steep slope towards the ice the oscillation would be greatly reduced and the moraines would be closely packed together, as is seen in interlobate areas. In wide flat areas, like the Saint Clair-Detroit and Maumee valleys, the amplitude would be at its greatest.

The general application of this idea to the oscillations that took place is plain on a comparison of the course of any two contiguous moraines of the series from their apexes in the center of the valley to their turning point in the interlobate. The Fort Wayne and Defiance moraines are nearly fifty miles apart at their apexes, but they converge as they rise toward the northeast until they are only eight or ten miles apart a few miles beyond Adrian. On this basis it would be expected, further, that the moraines themselves would be comparatively wide and flat where the amplitude of oscillation was great and *vice versa* Here again there is some evidence of agreement of fact with theory. With the period of oscillation at 10,000 years and the amplitude at 100 miles, which appears to have been its approximate measure after passing Fort Wayne, the five-mile moraine belt would be occupied by the ice-front about 1345 years, and a ten-mile belt about 1920 years.

THE CHARACTER OF THE GLACIAL OSCILLATIONS AS REVEALED BY THE DRIFT.

Assuming that the moraine series was produced by a climate oscillation it becomes a matter of the highest importance to discover if possible what the character of that oscillation was Did the ice-front merely retreat and halt in the simplest possible rhythmic fashion, or did it follow a more complicated movement of alternate retreats and readvances with halts between? It would be expected that the way in which it was built would make some difference in the form or shape of a moraine. If the moraines took any dominant or common form, and if that shape corresponded to one that would result theoretically from some particular process, it would be fair to presume that that had been the method of their building.

At a first glance it would appear that the moraines show no recurrent features that are particularly suggestive in this respect, and it must be admitted that many of them, perhaps the majority, do not. At least they do not show such features clearly enough to be readily recognized. But there are some of the

moraines that do show a marked tendency to take a particular form, and it is upon these that we must rely.

Here again it is necessary to recur to the law of the higher value of the simplest phenomena as a basis of interpretation when compared with those that are more complex. If in the present state of our knowledge we go to the compounded moraines of interlobate areas, or to the more or less obscure moraines of the mountains or hilly eastern states, it will be found very difficult to reach any satisfactory conclusion. But some of the moraines of northern Indiana, northwestern Ohio, and southeastern Michigan present the utmost simplicity of form, and were built under the operation of forces acting in the freest and simplest way possible. Upon these moraines, and especially upon those of them that seem to be most typical in their simplicity, I rely mainly for the conclusions reached.

The moraines of northeastern Indiana have been studied in detail by Professor C. R. Dryer, from whose report I quote as follows:

> The peculiar topography of the Wabash-Erie region in Indiana would be strikingly shown by a section along any line radiating southwesterly or northwesterly from Paulding, Ohio. Such a line would run nearly level across the Maumee Lake bottom to the Van Wert and Hicksville Ridge, then rise 80 to 100 feet in four or five miles to the crest of the St. Marys and St. Joseph moraine, then fall fifty feet in about one mile, then cross a level interval of from one to ten miles, then show a second gradual rise and more abrupt fall, across the Wabash-Aboite moraine, and the second terrace averaging about sixty feet higher than the first. In the southern portion two more terraces lie beyond the Wabash Ridge.[1]

[1] Sixteenth Ann. Report of Indiana State Geologist, 1888, p. 123.

My attention was first called to the remarkable series of terminal moraines in northeastern Indiana and northwestern Ohio by the work of Professor Charles R. Dryer in the summer of 1886. As assistant to the state geologist, Professor Dryer was at that time making a survey of the northeastern counties of Indiana. Some acquaintance with the features of eastern Indiana southward as far as southern Randolph county and also with the region around Saginaw Bay in Michigan led me to extend the series provisionally, recognizing its probable incompleteness, to those regions. The idea that these moraines might mark precessional variations of climate was adopted by me then as a tentative hypothesis. The drift of opinion since then among American geologists, however, has been largely against anything like so

This is distinctly the character that should be expected in moraines built at a climax of advance in which the advance, the halt and the subsequent retreat take place after the manner of the cold climax of an oscillation like that shown at *A* in Fig. 1 above. The crest of the ridge is toward the front edge, the back slope is long and gentle, while the front slope is shorter and

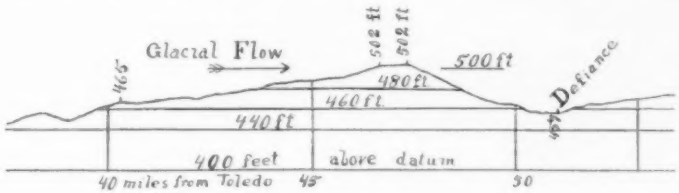


FIG. 2. Profile of Defiance Moraine.

steeper. This type of moraine is well illustrated in cross section by the profile of the Wabash Railway as it passes over the Defiance moraine east of that place. This is shown in Fig. 2.

As shown on this profile the crest of the moraine rises above

liberal an allowance of time for the glacial retreat as this hypothesis would seem to require. Moreover the moraine series remained fragmentary and incomplete until a year or so ago, so that there was not a sufficient foundation of fact to warrant the presentation of the idea. Nor had the remarkable Greenland explorations of Chamberlin, Salisbury, and others furnished the present strong foundation for the idea of slow motion of ice-sheets and slow transportation and deposition of drift. Without adopting the idea of precession as a cause, Professor Dryer fully recognized the general significance of the moraines, as the following words from his report show. After speaking of the possibility that each moraine marks the culmination of a separate glacial epoch, he says: "It seems more probable, however, that they are moraines of recession and mark halting places in the retreat of one and the same ice lobe. When their uniformity of mass, strict parallelism and occurrence at regular intervals are taken into account, the whole arrangement will perhaps prove to be unique among the glacial phenomena of North America. Their greatest importance lies in the evidence which they afford of regular periodical oscillations of climate. The outer edge of the ice lobe occupied a certain position long enough to form a moraine five miles wide and 100 feet high; it then fell back fifteen miles and occupied another line long enough to form a similar moraine. These alternating halts and retreats were repeated four or five times, the last retreat being thirty [fifty?] miles, and the last moraine, the Blanchard Ridge of Winchell, being smaller and less symmetrical" (p. 124).

its base somewhat more than forty feet, but the real crest is somewhat higher than the railroad track. The front or western slope is about two and a half miles long and the eastern or back slope about seven miles. It has been suggested that the moraines that show this form owe their steeper front slopes to the action of marginal glacial rivers which have carried off the deposit on that side. No doubt there was a slight influence of this kind in some cases, but there certainly was none in the case of the Defiance moraine, for it was laid down in about sixty feet of still water (glacial Lake Maumee) and there was no chance for a stream to act until the ice-front had retreated beyond Detroit nearly to Port Huron. While the Leipsic beach was being made the water still stood about thirty feet deep at Defiance, and it was only when it fell to the level of Lake Whittlesey (Belmore beach) that marginal rivers began to exist. The depression shown at Defiance in the profile is the bed of the Maumee River which began to flow at the same time. But the Maumee is a much larger stream than Tiffin or Bean Creek that comes in from the north along the moraine front, or the Auglaise River, which comes in from the south in the same relation. Formed under such circumstances it is obvious that the Defiance moraine was originally shaped in the building as we find it now, and does not owe its form to the action of a border river. Part of the Saginaw moraine, between Ubly and Cass City was probably steepened by the large rapid outlet river which flowed along its front, but apparently none of the other moraines of this type were notably affected in this way. The rest of the Saginaw moraine is a fine specimen of the type here referred to.[1]

This character of the moraines, however, is not confined to the particular tri-state area mentioned above. The same general type is only a little less distinctly developed in several other places, and is recognized by other observers. Mr. Leverett,

[1] Some account of Lake Whittlesey and the Saginaw and Port Huron moraines with brief mention also of the Toledo and Detroit moraines may be found in "Correlation of Erie-Huron Beaches with Outlets and Moraines in Southeastern Michigan," Bull. G. S. A., Vol. VIII, 1897, pp. 31–58. Also "Glacial Succession in Eastern Michigan," abstract in Am. Geol., Oct. 1896, p. 234.

speaking of the glacial drift of the northeastern third of Illinois, says:

> In the portion of the state covered by the newer drift there is a succession of morainic ridges formed by the ice-sheet during its retreat from the Shelbyville moraine. These ridges are separated by drift plains or basins from a mile or two up to thirty or forty miles in width. These plains usually show a gradual rise on their landward (west and south) borders, while on the iceward borders (toward the Lake Michigan basin) they are found to rise abruptly to a moraine. The streams which now drain this region naturally choose the axes of these basins for their main channels while the slopes carry the tributaries. It is the long slopes on the west and south, and the short slopes on the opposite side which have caused the tributaries of the streams to be mainly from the west and south.[1]

It will be noted that Mr. Leverett speaks of the slopes of the plains rather than of the moraines. Each moraine, however, may be regarded in some sense as the projecting upward edge of the gently inclined plain that merges with its back slope. Professor Todd notes this relation in his description of the moraines of Dakota where he says:

> It is assumed that the reader is familiar with the generally recognized features of drift formations, such as the undulating topography and the series of drift deposits, covering an area with successive layers of till in a manner which might be compared to a nest of spoons of assorted sizes, the smaller lying inside the larger. Of these spoon-shaped deposits, the moraines form the outer rims.[2]

It is very gratifying to be able to add to the weight of the foregoing opinions that of Professor Chamberlin, whose study of glacial problems has been close and prolonged, and whose experience in observation is probably wider than that of any other one man. It is hardly less than remarkable that his views of the glacial retreat should accord so closely with the requirements of the hypothesis here presented.

But so far as known to the writer this manner of glacial

[1] "The Water Resources of Illinois," by FRANK LEVERETT. Extract from 17th Ann. Rep. U. S. Geol. Surv., 1895–6, p. 13. Also in "Pleistocene Features and Deposits of the Chicago Area," Chicago Academy of Science, Bull. No. II, May 1897 p. 17.

[2] "The Moraines of the Missouri Coteau and their Attendant Deposits," by JAMES E. TODD, Bull. U. S. Geol. Sur. No. 144, 1896, p. 11.

retreat has not been associated by Professor Chamberlin with the causes here suggested. According to his view the drift of each main ice invasion was laid down in imbricate fashion; that is, there was a continual oscillation with moderate readvances as the general retreat progressed, so that the drift was laid down in successive overlapping sheets somewhat like the weatherboards on a frame house, or the shingle rows on a roof. In Geikie's *Great Ice Age*, under "The Imbrication of the Drift Series,' beginning on page 736, his views are given as follows:

> The drift deposits of the great plain region of North America may be looked upon as a series of sheets overlapping each other in imbricate fashion; the outermost disappearing beneath the next inner, and this, in turn, dipping beneath the succeeding, and so on. The outer uncovered zone of each sheet retains its original form, except as modified by superficial agencies, but the inner buried zone was much modified by the over-riding ice during the later advances. In a general view of the drift, it is important to grasp clearly this conception of the overlapping of the sheets, and to distinguish this imbricate structure from the simple stratigraphical superposition of marine sediments on the one hand, and of simple morainic corrugations following each other in concentric recessional lines on the other. It is, furthermore, important to observe that this is only a superficial conception of the drift series. Theoretically, there are at least two of these imbricate series for every period of glaciation, and the order of imbrication takes on opposite phases. During the first part of the glaciation, when the ice on the whole was extending, though by alternate advances and retreats, the later were generally greater than the earlier advances. During the succeeding stage, however, when the ice was, on the whole, retiring (though by oscillations) the later advances generally fell short of the earlier. In the case of the lower or older series of glacial accumulations, therefore, the later deposits generally reach farther south than the earlier ones, whereas, during the recessional stages of glaciation, the earlier sheets extend farther south than the later. These two imbricate series of sheets of contrasted order represent the two great halves of a period of glaciation. If there were two or more entirely distinct periods of glaciation theoretically the double imbricate series repeated itself accordingly. . . .

There is one other class of facts that may ultimately be added to the proof of readvances in the oscillations. Bowlder belts, at least in certain situations, are believed to indicate readvances. Respecting the source of the bowlders themselves it seems safe to say that ninety-nine out of every one hundred in

western Ohio, in Indiana, and Illinois are of Canadian origin, and nearly all are of the hardest crystalline varieties. Considering the dominant englacial mode of transportation, the continual and very complicated changes in the direction of glacial flow and the dispersion from the lobate axes, it becomes extremely difficult, if not altogether impossible, to account for the bowlder belts except by the intervention of some later agency of bowlder concentration—some agency that operated near where the bowlder belts are now found. It seems impossible that any marked bowlder belt could have been brought all the way from Canada with the bowlders in such close relationship as that in which they now lie. Some of the bowlder belts of southwestern Ohio, southeastern and western Indiana are very pronounced in their development. It is conceivable that they might have been formed by the marginal concentration of superglacial or englacial bowlder trains, but it is hard to think of those trains as coming directly all the way from Canada.[1] The distribution of bowlder belts is peculiar and indicates that the conditions of their production are exceptional. One moraine may show a well-formed bowlder belt, while its neighbors parallel with it in front and behind have none. The diverse composition of the bowlders seems also to be against the idea of concentrated bowlder trains. In short, it would seem that we must look much nearer than Canada for the cause of their very local concentration. The only local cause that seems available grows out of the relation of the readvancing ice-front to powerful lines of drainage at or near the edge of the ice. If, during the building of a terminal moraine, a powerful stream of water sweeps past the front of the ice so as to carry away the finer material the bowlders may be left on the surface in greater numbers than usual. Several of the well-known abandoned outlets have more or less of this appearance. But where this is the whole process the bowlders remain in a low position with respect to the surrounding lands. If, however, a readvance of the ice

[1] "Bowlder Belts Distinguished from Bowlder Trains—their Origin and Significance," by T. C. CHAMBERLIN. Bull. G. S. A., Vol. I, 1890, pp. 27–31.

takes place the bowlders in the channel may be gathered up and transported some distance and finally be deposited on or in a rugged hilly moraine even to its topmost parts. In being carried forward the bowlders may be more or less dispersed, or they may be concentrated, or neither of these effects may appear. In each case it depends mainly upon the relation of the river

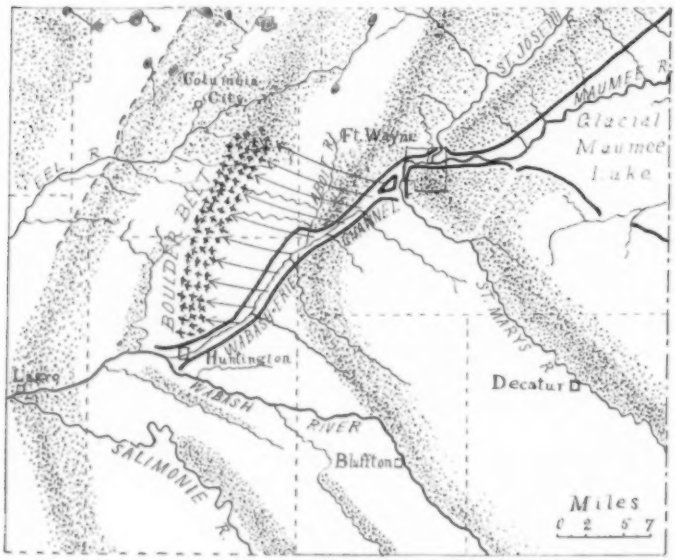


FIG. 3. Showing relation of the Whitley bowlder belt to the Wabash-Erie channel.

channel to the direction of ice-motion. If the channel were straight and also normal to the ice-front the readvancing ice would carry the bowlders all forward down the channel and concentrate them in a pile where it stopped. If the channel lay athwart a pointed ice-tongue and close in front of it, the readvance would disperse the bowlders somewhat. There is a bowlder belt in Whitley and Huntington counties, Indiana, which may be due to partial concentration by a readvance diagonally across the bed of a great river corresponding to the stream that

afterwards existed as the outlet of the glacial Maumee lake. The accompanying sketch map shows the relation. Dryer and Leverett show this belt on their maps.[1]

The disposition of this belt seems to show that the ice-front had retreated at least to Fort Wayne from the moraine next west of the bowlder belt in Whitley county, and halted while the large river excavated a channel about where the present old outlet bed is between Fort Wayne and Huntington. Then by a readvance the bowlders which had been left in this bed were carried forward by the ice, which moved in a direction normal to the ice-front, but diagonally across the river bed, and deposited them in the Whitley morainic bowlder belt. If this took place, then it is plain that the ice-front had retreated to Fort Wayne and that it readvanced over more than half the space it had just uncovered at the preceding retreat which was, therefore, not less than thirty miles.[2]

This interpretation of the Whitley belt is not yet a sure inference, for further and more particular investigation will be required to fully verify or disprove it. The Montgomery-Benton county belts seem to be somewhat similarly related to a readvance over a part of the Wabash River bed, and possibly to a former river bed about where Wild Cat Creek is now, and the Iroquois belt may have had a similar relation to the Tippecanoe River or to a glacial river that crossed from the Kankakee to the Wabash farther west, but was obliterated by the readvance.

[1] DRYER in 18th Report of Indiana State Geologist, 1894, p. 84. LEVERETT in the "Inland Educator" (Terre Haute, Ind.), for August 1896, opposite p. 24. DRYER shows only that part of the bowlder belt which lies in Whitley county; LEVERETT shows it extending on southward nearly to Huntington. The accompanying sketch is compiled from their maps.

[2] The range or amplitude of oscillation may have been considerably more than thirty miles. Indeed, after the ice-front left Fort Wayne it must have been greater, for the four intervals from this place to Port Huron are almost exactly fifty miles each. The amplitude of oscillation was probably twice this or a little more — 100 miles or over — if the Whitley bowlder belt can be relied upon to indicate a readvance from Fort Wayne. The probable cause of the difference in amplitude east and west of Fort Wayne will be discussed later on.

On the whole, the character of the oscillation as one that was always accompanied by a readvance after recession seems to be well established by several different lines of evidence and by several of the most experienced observers.

THE PROBABLE RATE OF ICE-SHEET MOTION.

The great ice-cap of Greenland bears a closer analogy to our own Pleistocene ice-sheet than any other ice mass yet studied. The observations of Peary, Chamberlin, Salisbury, and others throw no uncertain light on the problems of ice-sheet motion as there exhibited. On this point Professor Chamberlin says:

> Lieutenant Peary has commenced a series of observations upon the movements of glaciers of the Inglefield Gulf region, both by instruments and by photographs taken at intervals. He found the daily movement of the Bowdoin glacier, the most active in the immediate vicinity of his headquarters, during the month of July to be four-tenths of a foot at the slowest point, and 2.78 feet at the fastest point, near the center, with an average of 1.89 for the whole.[1]
>
> The movement of the majority of the glaciers in that region is very much slower; indeed, in most cases it is obviously exceedingly slow. Many of the ordinary signs of movement are absent. In front of the Fan glacier there are cones of granular ice brought down by the surface streams, and also embankments of old snow, soiled, granulated, and half solidified into ice, as though at least a year old, all of which lie banked against the terminal face of the glacier without any indication of movement on its part since their formation. As these lean against the face to heights of thirty or forty feet at least, it is obvious that there had been no melting of the base of the extremity to counteract the effects of advance. Phenomena of similar import were observed in several other glaciers. The very firm impression was given by such physical signs that the average rate of movement of the glaciers of the region is very slow. At the head of the gulf are a few glaciers which produce large icebergs and which must be notable exceptions to the prevailing slowness of motion.[2]

[1] According to Professor Chamberlin (JOUR. GEOL., Vol. V, No. 3, 1897, pp. 229–232), the Bowdoin glacier is six or eight miles long, about two miles wide in its lower part and descends between 2000 and 3000 feet. After its separation from the ice-cap by a somewhat steep fall, the Bowdoin glacier becomes essentially Alpine in type. Hence it does not furnish a criterion that can be applied to the ice-cap itself. Slow as is the advance of the Bowdoin glacier, it is probably much faster than that of the edge of the main ice-cap.

[2] Recent Studies in Greenland, Bull. G. S. A., Vol. VI, 1895, pp. 216–217.

Again, discussing glacial motion more broadly, Professor Chamberlin says, referring to Greenland:

> No average measurements, nor anything approaching to average measurements, have been made. The high rates of movement of the Jacobshaven glacier, as given by Helland, and of the Great Karajak glacier, as given by Drygalski, and other similar measurements, are not at all questioned, but these are quite exceptional, and almost as far as possible from being representative. They exhibit extraordinary movements through deep constricted straits, where the ice is forced by the vast accumulations of great areas in the rear, and where the warm season appears to exert its earliest and greatest effects. The amount of ice discharged in the form of bergs from these two glaciers is very much greater than from any other known points on the ice-front of Greenland. It is perfectly obvious that the average border of the Greenland ice-sheet does not move at a rate even distantly approximating that of these two straits. If it did so, the whole coast of Greenland must be overwhelmed almost immediately, because the competency of the summer heat of that region to hold back the edge of the ice by melting is very slight. Drygalski estimated the annual surface melting at seven feet. Even this is much greater than the annual surface melting of the Inglefield Gulf region, judged by that of 1894. While estimates are few, and even these may need much qualification, it is nevertheless certain that the average movement of that portion of the border of the Greenland ice-cap which lies upon the land is extremely small. Of that portion which ends in the sea only a small fraction has a high rate of motion, as is shown by the lack of activity in the discharge of icebergs. When it is considered that the land border is very much greater than the sea border, and that of the sea border a portion has a relatively slow movement, it will be evident that the average rate of movement for the border of the great ice-sheet of Greenland cannot be high; and the average rate of this border is the nearest available analogue to the border movement of the still more extended periphery of the ancient American or Laurentide glacier.[1]

There can hardly be a doubt of the great value of the Greenland observations in their bearing on the conditions attending the Laurentide glacier that invaded the United States. It will be observed that most of the measured rates of motion reported by Peary, Chamberlin, and Salisbury are of ice tongues flowing out a few miles from the main cap down valleys generally

[1] The Glacial Lake Agassiz, by WARREN UPHAM. Monograph XXV, U. S. Geol. Survey, 1896. Topic entitled "Alternative Interpretations," by T. C. CHAMBERLIN, pp. 248–249.

steep. None of the measurements are of a broad lobate front such as any one of our great lobes presented south of the lake basins. One would expect the rate of motion to be still slower where it was evenly distributed along a broad front.

There is another character of the borders of the Greenland ice that is a valuable aid in interpreting rates of motion. In all glaciers that move at a relatively rapid rate, as is the case with most Alpine, and fiord, or berg-producing tongues, the ice is cracked and broken deeply, and shows a rough, tempestuous surface with crevasses more or less numerous and deep. Slowly moving glaciers do not show much of this character, but are comparatively solid and smooth down to their ends, and this is the character of nearly all the glaciers that end on land as described and shown in photographic illustrations by Chamberlin and Salisbury.[1]

There is a circumstance connected with some of the moraines in the Cincinnati-Mackinac series which seems to leave little doubt of the slow motion in the great ice-lobes that made them. According to Professor Dryer the front of the Erie ice-lobe at Defiance, Ohio, stood in about sixty feet of water, that being the deepest point of Maumee Lake. But since the recent recognition of the low, faint, water-laid moraines it is found that the front of the ice halted successively at Toledo, Detroit, and Port Huron, in each case standing in about 200 feet of water. The points mentioned mark the apex of the lobe at each halt, and the place of the water-laid moraines and their land-laid extensions seem to show that the ice fitted itself to the valley relief in each case almost as perfectly as it would have done if the water had not been present. This fact throws much valuable light on the condition of the ice when it stood in these positions. Baldwin, Upham, and others have supposed from

[1] Glacial Studies in Greenland, by T. C. CHAMBERLIN, JOUR. GEOL., Vol. II, Nos. 7 and 8, 1894; Vol. III, Nos. 1, 2, 4, 5, 6, and 7, 1895; Vol. IV, No. 5, 1896. Recent Glacial Studies in Greenland, Bull. G. S. A., Vol. VI, 1895.

The Greenland Expedition of 1895, by R. D. SALISBURY, JOUR. GEOL., Vol. III, No. 8, 1895; Salient Points Concerning the Glacial Geology of North Greenland, JOUR. GEOL., Vol. IV, No. 7, 1896.

certain evidence they have adduced that lobes ending in glacial lakes broke up like calving fiord tongues and floated away so rapidly as to make their fronts concave.[1] Chamberlin seems to show this effect by two moraines in the basin of Lake Agassiz on his map in Geikie's *Great Ice Age*, 1894 (opposite page 727). Whatever the facts may be for the Lake Agassiz basin, this was certainly not the case with the Huron-Erie lobe. The fact that the ice was able to keep its place in 200 feet of water almost as though no water were present shows (1) that it was not broken and deeply crevassed into loose blocks that might easily float away, but was comparatively solid and compact, proving (2) that its motion must have been of the slow order rather than of the rapid; (3) that its thickness at the edge as it then existed must have been considerably more than 200 feet, probably not less than 300 or 400 feet; (4) that although the front must have been undercut and broken off to some extent by wave action, flotation, and melting in the lake water, this process did not become a factor of sufficient importance to seriously disturb the line of the ice-front as determined by land relief alone. The Saginaw lobe shows the same ability to conform to the land relief while standing in water at the Saginaw moraine over 150 feet deep.[2] I am led to believe, therefore, tentatively, that the motion of the ice-sheet while building the moraines of recession was very slow. That is, it was so slow that the lobes as they crept along remained essentially solid to their extreme edges.

[1] Glacial Lake Agassiz, Monograph, by WARREN UPHAM, Plates XVII and XIX. Pleistocene History of the Champlain Valley, by S. P. BALDWIN, Am. Geol., Vol. XIII March 1894, p. 181.

[2] Nansen, in his "Farthest North," Vol. II, p. 339, describes a glacier-front of this kind in Franz Josef Land in the following terms: "We were soon underneath the glacier, and had to lower our sail and paddle westward along the wall of ice, which was from fifty to sixty feet in height, and on which a landing was impossible. It seemed as if there must be little movement in this glacier; the water had eaten its way deep underneath it at the foot, and there was no noise of falling fragments or the cracking of crevasses to be heard, as there generally is with large glaciers. It was also quite even on the top, and no crevasses were to be seen. Up the entire height of the wall there was stratification, which was unusually marked."

There are some writers who make the whole period of glaciation very short. Mr. Upham believes that Lake Agassiz "endured only a thousand years or less," and he allows "only a few (perhaps four or five) thousand years" for the entire glacial retreat, including the whole Champlain period of submergence and most of the later reëlevation of the land.[1] But it seems to me that both fact and theory as they stand today clearly incline toward a long rather than a short time.[2]

TRANSPORTATION AND DEPOSITION OF ENGLACIAL DRIFT.

If we turn to the best available evidence bearing on the manner and rate of drift transportation by the ice-sheet we meet with facts tending to the same general conclusion, viz., that the building of the moraines was a very slow process. The rate of glacial motion is necessarily a function of the rate of drift deposition. If it is sufficiently clear that the ice motion was very slow we have that much gained towards a determination of the probable rate of moraine building. The other function is the drift load, and we have now to consider what evidence can be brought to bear upon it and also what theoretical considerations indicate as the probable truth.

Here again the Greenland ice-sheet is the closest available analogue and the significance of its indications relating to drift load and deposition are well set forth by Professor Chamberlin. On these points he writes as follows:

> That considerable débris is borne in the basal portion of the ice is not questioned; indeed, the term, "englacial drift" was proposed by the present writer in recognition of its importance. Our best evidence of the amount

[1] "View of the Ice age as two Epochs, the Glacial and Champlain." Proc. A. A. A. S., Vol. XLIV, 1895, p. 144. Also Am. Geol., XVI, August 1895, p. 107. For duration of Lake Agassiz see also "Glacial Lake Agassiz," by WARREN UPHAM. Monograph, pp. 241–242.

[2] In studying the history of such a glacier as the Muir of Alaska with its relatively rapid advances and retreats ("Glacier Bay and its Glaciers," by H. F. REID, 16th Ann. Rept. U. S. Geol. Survey; map opposite page 454), and like many of those that calve icebergs in Greenland, it must be remembered that the conditions of their motion are not at all like those of an ice-sheet and that they do not furnish safe criteria for interpreting ice-sheet motion.

and distribution of this is derived from the continental glacier of Greenland. It is there observed that débris prevails in the lower 50 or 75 feet of the ice-sheet, and occasionally reaches up to 100, or perhaps even 150 feet. The amount of this débris, if it were let down directly upon the glacier's bottom by melting in situ without concentration by the forward motion of the ice, would be measured by a very few feet, or by a fraction of a foot. The forward motion of the ice concentrates this at its edge, so that it may there reach, theoretically, any dimension, entirely without regard to its amount in any given vertical section of the ice. The thickness of the deposit formed from the englacial drift is quite as much dependent upon the length of time during which the edge of the ice remains at one line as upon the amount of drift which the ice may carry in any given vertical section. No safe inferences from the thickness of deposits of englacial drift can therefore be drawn with reference to the amount of englacial material present in any given portion of the glacier. If the ice were absolutely stagnant the deposit of englacial drift would be precisely that which was held in the ice above the point of deposit. If there was any forward motion of the ice while it was being melted away, there would necessarily be a concentration. If there be one foot of englacial débris in a given section and the ice moves forward 40 feet while the external heat causes a retreat of 1 foot, the englacial deposit should be 40 feet deep. The thickness of the englacial drift may therefore be quite as much an expression of prolonged time as of a large content of débris within the ice.

Referring to the manner in which the englacial débris becomes at length exposed and deposited Professor Chamberlin, continuing on the next page, says:

> Instead of rising toward the surface of the glacier, it is believed, on the basis of observations in Greenland, to pursue a course nearly parallel to the base, on the whole, and to come out at the extremity of the glacier. To some slight extent it may become superglacial by ablation, but only to a limited degree.[1]

Again, describing more specifically the phenomena in Greenland, Professor Chamberlin says:

> The débris belts are essentially parallel to the base of the glacier. They are chiefly confined to the lower 50 or 75 feet; sometimes they prevail up to 100 feet and rarely beyond. I think 150 feet might be named as a rather extreme limit. They are more abundant at the sides of the lobes than at the center, a fact that is significant in indicating the introduction of a notable part of the débris after the lobes were formed. In consonance with this the débris appears to be most abundant in the glacier-lobes which descend as cataracts or crowd between closely hugging cliffs. If, standing in front of a

[1] "Glacial Lake Agassiz," Monograph, pp. 249 and 250.

glacial lobe, the dirt bands are traced, many will be found disappearing at the cataracts, or the embossments of the bottom, or at the spurs on the sides.[1]

The general impression produced by such conclusions as these is that an ice-sheet probably carries somewhat less englacial drift than the tongues that, like those of Greenland so far described, branch off from the main sheet and descend several miles and 2000 or 3000 feet down ravines or constricted valleys. The tongues certainly have better opportunities to gather débris than the bottom layers of the main cap. And the force of this impression is greatly increased when we think of an ice-cap that deployed over so smooth a plain as did, for the most part, the Laurentide glacier in the area here considered.

Mr. Upham inclines to the opinion that "englacial drift was carried up through the lower quarter or third part of the ice-sheet, where, as in Manitoba, it was probably a mile thick."[2] But, as Professor Chamberlin has said, there seems to be no reason to suppose that the thickness of the bottom débris-laden layers bears a fixed ratio to the total thickness of the ice. Indeed, from the very fact that the upper part of a glacier moves forward faster than its lower layers, it follows that the bottom layers cannot rise beyond a very limited extent, except by overthrust in consequence of flow over high points or embossments that project upward into the ice. In passing over high obstructions high englacial drift may be introduced. But the amount of such drift appears to be really insignificant, and it even then becomes superglacial only after it has moved with the ice far enough forward into the peripheral zone of ablation to have had all the ice that overlies it melted off, or until it reaches the very edge and is thrust upward over a moraine or other obstruction.

Those who have not seen glaciers have often been much

[1] "Recent Glacial Studies in Greenland," Bull. G. S. A., Vol. VI, 1895, page 205. Contrast with these ideas the opinion of MR. UPHAM, where he says, speaking of the great Leaf Hills moraine in Minnesota, that "perhaps not more than fifty or even twenty-five years [were occupied] for amassing these morainic hills 100 to 350 feet high on a belt 3 to 5 miles wide!" ("Glacial Lake Agassiz," Mon., p. 242).

[2] "Sublacustrine Till," W. UPHAM, Am. Geol., Vol. XVII, June 1896, pp. 374–375.

deceived as to the amount of englacial drift by the highly deceptive appearance of pictures of débris-laden, melting ice-tongues. Chamberlin and Salisbury both draw attention repeatedly to the effect of the spreading of fine dirt so as to blacken the whole ice wall. When small streams of clear water wash this away, or the dark surface has been removed with a pick, comparatively clear ice is seen beneath, and yet some of these layers or thin laminæ which they contain, may be the very ones that were supplying the blackening material. Large masses of englacial drift are rare and their forward motion is extremely slow, certainly much slower than that of the clean ice above, except where they occur, still more rarely, as lenses relatively high up in the glacier so as to have a considerable thickness of clear ice beneath them. In short, it seems to be shown that englacial drift is a far less voluminous constituent of ice-sheets than has been supposed by many. It keeps its importance, however, as almost the only means of drift transportation by continental glaciers like that which invaded the United States. But except under peculiar circumstances the amount in any given section of ice is almost insignificant. When all the circumstances are taken into account it seems probable that the load of débris is as great or greater in the Greenland tongues than it was in the Laurentide lobes in Ohio and Michigan. The coast of Greenland is mountainous. The ice flows out among many nunataks and along the base of high cliffs, and no doubt overrides many knobs and peaks and precipices from all of which it gathers material in such a way as favors its becoming superglacial or englacial. Then, too, the exceedingly rough country is favorable to the production of high overthrusts by which the bottom layers with their débris may assume relatively elevated positions in the ice.

When the ice-front was in Ohio or Michigan there was no chance for the formation of lateral moraines from cliff-fallings, nor of medial moraines from the detritus of nunataks. At that stage of glaciation the field of ice stretched away to the north-northeast without a break, and no land was exposed back of the

edge. In Canada some of the path of the ice was rather rough, but not in any sense comparable in this respect with most of the coast of Greenland, and it was all deeply overridden at the time the ice reached across Lake Huron to points farther south. It follows that substantially all the northern drift of Michigan, Ohio, Indiana and Illinois was carried forward from Canada englacially. But the larger portion of the drift south of the lakes is of local origin, derived from rocks near by. This region, as the last ice-sheet found it, was probably a comparatively smooth drift plain, made so by earlier Pleistocene ice-sheets Almost the only way that local débris could become englacial was by being taken up, absorbed or incorporated directly into the lower layers of the ice as the glacier moved along. Under the great pressure of ice, hundreds or perhaps thousands of feet deep, this process must have become more or less effective. It seems almost certain that substantially all the drift south of the lakes was transported englacially, and in only the lower layers of the ice-sheet. The maximum load which can be carried in the bottom layers of the ice without overthrust cannot exceed a certain amount for a given pressure and rate of glacial flow, and that amount is probably not large. When the bottom layers become overloaded they clog beneath the ice and cease to move, while the cleaner upper ice forms a plane of shear above the clogged layers and overrides them. Professor Salisbury, writing of the glaciers of Greenland, says:

> Professor Russell has called attention to the fact that the movement of ice is influenced by the amount of débris which it carries. This doctrine finds abundant confirmation in the north. The lower part of the ice, which is well charged with débris, or altogether full of it, seems to virtually lose its motion and to become the bed over which the upper ice passes. It is not possible to say that its motion is absolutely lost, but many phenomena seem to make it certain that the upper portion of the ice of a glacier passes over the lower débris-charged portion in the same way that it passes over a rock bed. The lower part of the ice in such cases becomes virtually an ice conglomerate, the mobility of which is certainly slight.[1]

[1] "Salient Points Concerning the Glacial Geology of North Greenland," by R D. SALISBURY. JOUR. GEOL., Vol. IV, No. 7, pp. 800–801.

It appears to be a plain inference, even in the case of the extremely slow motion of the Greenland cap, that however slowly the upper layers of the ice move, the débris-laden bottom layers move still more slowly. Even in a fiord tongue which moves 50 or 100 feet a day, if the ice is 1000 to 1500 feet or more deep the extreme bottom layers may move quite slowly.

The principles involved in basal clogging have been well brought out by Professor I. C. Russell. He reduces them to this proposition: "The rate of flow of glacial ice, under given conditions, will depend upon the percentage of débris commingled with it, and be least where the percentage is greatest."[1] For our present purpose this law may be advantageously restated in terms of drift transportation and deposition rather than ice-motion, thus: Whether the basal layers of a glacier will absorb or deposit débris at a given place or pass over without doing either, depends on their carrying an underload, an overload, or just an even full load at the existing velocity and pressure.

Under deep ice, however, the building up of ridges or prominences like terminal moraines, by the clogging of débris-laden bottom layers, would seem to be impossible, because the tendency there is to wear down and abrade every prominence of the land that is overridden. Clogging under deep ice probably occurs to some extent, but only by the shearing off of thin bottom layers which do not remain as subglacial prominences. Hollows of the land surface would tend to be filled up by clogging, and a mass of débris once dropped in such a place would tend to stay there unless the peculiar and rare conditions which lead the ice to scoop out basins came into play. While the general truth of Professor Russell's proposition is plain, and the principle stated is one of great value, it may be doubted whether it can have such a function as he supposes when he suggests that it was the determining cause of the moraines of recession and their peculiar distribution.[2]

[1] "The Influence of Débris on the Flow of Glaciers." JOUR. GEOL., Vol. III, No. 7, pp. 823–832.

[2] In a footnote to his article (page 831) Professor Russell makes the following

The great Malaspina glacier of Alaska, so well described by Professor Russell, belongs to the Piedmont type, and is probably

suggestion: "That a series of terminal moraines in a formerly glaciated valley, or a similar succession of ridges left by a continental glacier, are not necessarily evidence of repeated climatic oscillations, but may have been formed during a uniform and continuous meteorological change favorable to glacial recession. That is, a débris-charged glacier may retreat for a time, then halt and again retreat, owing to its terminus becoming congested with foreign material, in response to a climatic change which would cause a glacier composed of clear ice to recede continuously and without halts."

It is hard to see how clogging of the lower layers could have the effect of building a ridge like a terminal moraine anywhere except at or very near the edge of the ice-sheet; and it seems certain also that the building of a great moraine must have required a relatively long duration of time — much longer than the building of the flat intermorainic plains of till. But under a uniform change of climate, as supposed by Professor Russell, it seems impossible to allow much more time for the building of a moraine than would be taken by a clear-ice glacier to retreat over an interval equal to the width of the moraine unless the formation of the moraine is supposed to begin under deep ice far back — at least several miles back — from the edge of the lobe. When the front of the Maumee ice lobe was at Fort Wayne the ice was probably 400 or 500 feet thick within a mile or two back from the edge, and its thickness increased to the northeast. From Fort Wayne to Port Huron there are five moraines in series with four intervals of about fifty miles each, and with wide till plains intervening. When the ice-front was just east of the Fort Wayne moraine, did basal clogging begin then at Defiance, forty-five miles back under the deep ice, or did the ice-front retreat from Fort Wayne to Defiance without clogging only to begin it again at the latter place? If the former, then we must set aside the law of heavy abrasion on subglacial prominences under deep ice. If the latter, then, as already pointed out, the time allotted for the building of the moraine is little if any longer than that which would be taken by a clear-ice glacier to retreat over a distance equal to the width of the moraine.

The Port Huron-Saginaw moraine is clearly traceable as a distinct individual from the highlands south of Georgian Bay, where it is about 1000 feet above the lake, descending to lake level at Port Huron, rising thence 300 feet to Ubly on the "thumb" of Michigan, descending again to lake level at Saginaw, rising again towards the northeast to the Au Sable River, and thence northwest nearly as far as Petoskey, where it is again about 1000 feet above the lake — a distance of over 400 miles. It seems hard to account for such a moraine by clogging alone, and for a series of them, the existence of which is a matter of simple inference from the facts now at hand, the difficulty becomes much greater. Speaking of the terminal moraines of the United States, Professor Chamberlin says: "Some of these have been traced several hundred miles in individual distinctness, and, by fair correlation, may be assumed to have been identified for a thousand miles or more." (GEIKIE's "Great Ice Age," 1894, p. 740.)

But even if basal clogging in itself could produce moraines, that process taken alone could hardly be the cause of such a marked and widespread periodicity in the phenomena. The continuity and great length of individual moraines shows that the periodic rhythm of the oscillations affected wide areas; indeed, there lacks but little to

the best modern example of it.[1] But this glacier is the dumping ground of hundreds of Alpine glaciers of the most pronounced type, all descending steep, short slopes from high mountains, and carrying heavy loads of débris—superglacial loads as medial and marginal moraines, as well as heavy englacial loads in their bottom layers. Contrasted with this the Laurentide glacier had no Alpine feeders whatever. Substantially all that it accomplished in the transportation and deposition of drift was done by its bottom layers in englacial fashion. The Malaspina apparently suggests nothing that would controvert the general conclusions drawn from other sources. For its most characteristic features are exceptional, and obviously do not apply to the Laurentide ice-sheet nor to ice-sheets in general.[2]

THE PROBABLE DURATION OF THE PERIODS OF GLACIAL OSCILLATION.

A little examination will show that no short period, such as 35, 100, or even 300 years will suffice for the building of the moraines. From Fort Wayne to Port Huron there are five moraines with four intervals of almost exactly fifty miles each. These constitute perhaps the simplest group in the whole moraine series. They have the widest and most regular intervals and some of them, when not too deeply water-laid, are the very best types of the structure characterizing deposition at a climax of readvance. The intervals are so wide, and the valleys in which

prove that it was of continental extent. From present indications it would seem almost certain that future investigations will establish this as a fact. But even supposing moraines to be formed sometimes by basal clogging, what could be the cause of such widespread periodic clogging if not climate?

[1] "Mt. St. Elias and its Glaciers," Am. Jour. Sci., Vol. XLIII, March 1892, pp. 169–182; "Malaspina Glacier," JOUR. GEOL., Vol. I, No. 3, pp. 219–245.

[2] Mr. Upham has recently enlarged and elaborated Professor Russell's suggestion, but apparently without throwing any new light on the obscure processes involved. (Am. Geol., Vol. XIX, June 1897.) He also endeavors to enforce the Malaspina glacier, which is a perfect example of the Piedmont type, as a criterion for interpreting the Laurentide ice-sheet or continental glacier. In this effort he even goes so far as to call the Malaspina glacier an ice-sheet—an application of the term which is clearly erroneous and misleading.

the broad Huron and later Erie-Huron ice-lobes advanced are so wide and smooth that the circumstances favoring simplicity were at a maximum.

Suppose it took the ice-front thirty-five years to retreat from the Fort Wayne to the Defiance moraine, receding at a uniform rate. That would be a little over twenty and a half feet a day. But this allows no time for retreat beyond Defiance, nor for the halt at the warm climax of retreat and the building of a moraine there of equal magnitude with that now seen at Defiance, nor for the readvance to Defiance, nor finally for the building of the Defiance moraine. If the Defiance moraine was built after a readvance and if the nature of the oscillation was such as shown in Fig. 1, then the time taken for the retreat from Fort Wayne to Defiance must have been only a fraction of the whole period of oscillation. We may measure the period of oscillation between the crests of the moraines, including always the destroyed moraine of the warm climax. We may assume further that the readvance is at least half of the previous retreat, and in this case the moraine of the warm climax next after the Fort Wayne moraine would be built at some point near Toledo and after it was finished the ice-front would readvance to Defiance. Then the first half of the period of oscillation would be measured between the crests of the Fort Wayne and Toledo moraines, and the second half between the crests of the Toledo and Defiance moraines. The two middle points of oscillation would then be half way between Fort Wayne and Toledo and half way between Toledo and Defiance. The first of these would be about at Defiance. On this basis the retreat from the crest of the Fort Wayne moraine to the middle point at Defiance would take one-fourth of the time of the whole oscillation and this includes half of the time of the building of the Fort Wayne moraine. On the basis of thirty-five years for the whole, this one-fourth part would occupy only about eight and three-fourths years, and surely half of this time would have to be taken to build half of the Fort Wayne moraine, and that would leave only four and three-eighths years for the ice-front to retreat fifty miles. The rate of retreat

would then average about 164 feet a day. And further, this retreat would have to take place in the face of the continual advance of the ice, so that the ice would have to melt back probably considerably more than 164 feet a day. Such a conclusion is manifestly absurd and its absurdity is only increased when we reflect that this is the average per day for the whole year. During the winter months there must have been not only no great amount of melting, but more or less readvance because melting ceased; and it is probably true that for some months in the spring and fall the forces of advance and retreat were about at a balance. Only for three or four months in summer would the forces of retreat be effective, so that substantially the whole annual retreat would have to take place during the summer and the rate of retreat would have to be at least four or five times the daily average for the whole year, or 700 or 800 feet or more per day. It does not help the matter much to change the period to 100 or even 300 years. For it would still be necessary to postulate a high rate of retreat—seventy or eighty feet per day during the effective melting season. If the period were 3000 years the rate would still be seven or eight feet a day at that season. With the period at 6000 years the rate would be three and a half to four feet a day, and at 12,000 years one and three-fourths to two feet a day.

We may suppose, if we choose, that at every turn of retreat the ice-sheet became completely disintegrated and broken up, at least over a wide marginal belt, on account of the suddenness and intensity of the increased warmth. But such a supposition savors of catastrophism and does not seem to be in the line of probable truth. The equilibrium between glacial accumulation and ablation must have been a very delicate one. There could be no wide departure from a balance of forces without a corresponding great change in the extent of the ice-sheet. Surely the climatic conditions which permitted the ice-front to stand for a long time at Fort Wayne were not greatly different from those that permitted it to stand at Defiance or at Toledo. There is no need of supposing that sudden or violent climatic changes produced

the oscillations. There is nothing in the phenomena of the drift that requires it, nor has anything been discovered in the behavior of the Greenland ice-sheet that suggests it. The summers were seasons of melting during the phase of advance as well as during that of retreat, and it may be doubted whether the most skillful observer could have detected any difference in the summers of the two phases unless he had made the most refined gauge measurements on the volume of the water discharged. Whether the ice-front would advance a little or recede a little or remain stationary during a long period of years was a matter of the utmost delicacy of adjustment. I doubt whether the average annual temperature for a period of years need differ more than two or three degrees to determine whether the ice-front shall stand at Fort Wayne or at Defiance.

Again, there seems every reason to suppose that the general advance of the ice-sheet was after the same manner as the retreat, only that the oscillations were reversed, and that it required the same duration of time. From the halt at Defiance the ice would retreat to Toledo, and then readvance to Fort Wayne, and so on. If this is a true assumption, then it would require us to suppose that the ice-sheet must be able to advance from Toledo to Fort Wayne in the same time, and hence at the same rate, as it is supposed to retreat over the same interval during the general recession. But it is manifestly impossible to suppose that the ice advanced at a rate of anything like 1000 or even 100 feet a day. The great wide lobe that advanced up the Maumee valley is not to be compared with the Muir, or the Karajak glacier, but rather with some part of the Greenland ice-cap that ends on land. It was not breaking off and floating away as bergs. It seems certain that its motion must have been very slow, probably not over two to five feet a day, even at the maximum.

But if it seems necessary to put the period of oscillation at 3000 years or more, it becomes a matter of comparatively small importance whether it be a little more or less. We have no means of knowing just what it was, but if 3000 years seems to be an extreme minimum and 6000 years seems better, there is no pos-

sibility of drawing the line just there and saying that it could not have been 10,000 years or even more. At the present day the combined weight of the facts, theories and analogies available to us seems to me to lean toward the conclusion that an oscillation period of between 5000 and 10,000 years would be the most satisfactory. If we take the Fort Wayne moraine to be five miles wide and the period of oscillation to be 5000 years, and if we suppose the period to be divided in two halves equal in time, one of advance to Fort Wayne over a space of fifty miles and the other of retreat from Fort Wayne over a space of 100 miles, then we may say in round numbers that it took 700 or 800 years to build the Fort Wayne moraine. If we take the period of oscillation to be 10,000 years, then it took twice as long.

THE SUPERPOSITION OF THE OSCILLATIONS UPON A GREATER AND MUCH SLOWER CLIMATIC VARIATION.

That there was a periodic oscillation of the ice-front of some kind or other needs no better proof than the simple fact of the existence of the moraine series itself. We have seen that by its influence upon climate precession would tend to produce a to and fro oscillation of the ice-front. We have seen also that there is a considerable amount of reliable evidence showing that the oscillations which took place did, in fact, have the character ascribed to precession. But if terrestrial climate had suffered no change from any other cause than that which produced the oscillations, then the ice-front would have gone on playing back and forth for an indefinite time over the same narrow strip of ground. But the moraines are distributed in a great series from south to north with intervals between them that are remarkable for their regularity, when due allowance is made for the influence of topography. This arrangement seems to be explicable only on the supposition that besides the oscillations there was another greater, slower change of climate in progress — many times longer in duration than the period of oscillation. Whatever their cause, the oscillations were obviously superposed upon this

greater, slower climatic change. After the grand climax of advance, when the ice of this epoch reached its farthest point south, the long retreat began and the oscillations that made the moraines of recession went on round after round during the slow progress or the greater change. This is a truth that stands out clearly on the face of the larger facts and is entirely independent of all theories as to the cause of the oscillations or of the greater change itself. Here again the moraines of recession, by their arrangement, and by the regularity of their intervals, help us to a partial insight into the nature of this greater change—the real cause of the Ice age. Not that they show us the whole cause fully and clearly, for they do not. But they show us enough of its real nature to enable us to eliminate several hypotheses that have been suggested, and so to narrow the range of discussion. The cause of the greater change must have been of an astronomical nature, and there is apparently no alternative.

In order to see the full import of the facts we must see just how the oscillation is related to the greater change. If the oscillations were regular (either with equal time intervals, or with time intervals that varied progressively at a uniform rate) and the greater change also regular (uniform or varying at a uniform rate) then the moraine series would tend to be regular, but if either one or both of the changes were irregular, then the moraine series would be irregular. To get a regular moraine series out of a combination in which either factor was irregular would be accidental, and an assumption that such a cause has produced the moraine series would be gratuitous and without reasonable foundation.

A careful analysis of the effect of topography in causing irregularities in the moraine series seems to show that the intermorainic intervals are not uniform, but increase from south to north. By reference to the map it will be seen that from the first moraine back to the ninth, or Fort Wayne moraine, the intervals are shorter than from Fort Wayne northward. The effect of topography can be best understood by considering the glacier in its advancing phase.

When the ice-front was at the Hagenville (15th) and Alcona (14th) moraines, the apex of its lobe in the Huron basin was in the present lake bed, and so cannot now be exactly located nor measured. But at the next halt the ice-front stood at the Port Huron-Saginaw moraine (13th). This is the first one now fully recorded on land. At that halt the ice was held back by the highlands south of Georgian Bay in Ontario, and by those southeast of Petoskey in Michigan, and it was also held back about fifty miles by the "thumb" of Michigan. With further advances the separated Saginaw and Huron lobes moved forward nearly equally at first, but soon the Saginaw lobe met higher ground, and slowed its pace, while the Huron lobe moved on more rapidly and met and blended with the Erie lobe coming up the Erie basin from the northeast, and the two advanced as one lobe up the Maumee valley. The ice clogged more and more against the high ground in southeastern Michigan, and began the building of a great interlobate moraine upon it. This obstructed the advance of the Maumee lobe pretty effectually on the northwest side, while the high ground along the south side of the Erie basin did not allow of much expansion on that side either. Hence the advance was mainly up the wide flat Maumee valley until Fort Wayne was reached. At this point there came an important change. The ice-front had almost reached the flat rim of the Erie basin along that part of the front line which extends from Fort Wayne eastward about 140 miles, nearly to Mansfield, Ohio—to the east side of the head of the Sciota valley. The subsequent advances found ample room for expansion in the most advantageous way; that is, in a southerly direction and down grade. The ice soon began advancing down the Wabash and White River valleys in Indiana, and down the Miami and Sciota valleys in Ohio. Besides, the Maumee lobe had now pushed so far ahead of the Saginaw that the obstruction on its northwest side in Indiana had been somewhat relieved. But before becoming distinctly segregated into four sub-lobes, the ice advanced for a few steps very evenly over the level summit plateau, forming the remarkably regular and concentric series of moraines south of Fort Wayne

and extending over into Ohio. At the sixth and fifth moraines the ice-front began to push slightly forward down the Miami valley, but the lobe did not become distinct until the fourth moraine. From that to the first moraine the Miami lobe developed more and more individuality. The first four moraines mark the fully developed lobe and the circumstances under which they were made probably accounts for the smallness of two of their intervals—eight and twelve miles between the second and third and the third and fourth respectively. The Miami was the smallest and narrowest of the four valleys and hence its ice-lobe was more cramped than the others. Besides, there was no such concentration of advance in the Miami valley as there had been before in the Maumee. The pressure was relieved by the other three lobes, while from Detroit and Cleveland to Fort Wayne the large Erie-Huron lobe was cramped by highlands on its sides and hence pushed forward in a comparatively long, sharp point.

In this discussion of the intervals we have followed the ice in its advancing phase. We have only to reverse the order of events to see that the influence of topography was substantially the same during the retreat.

This, as it seems to me, is the true explanation of the variations of the intermorainic interval, and it indicates that the narrow intervals which prevail from the first to the ninth moraines are not out of harmony with the wider intervals from the ninth to the thirteenth. The shorter intervals of these moraines do not indicate, as might be supposed, a radical difference in climatic conditions, nor of amplitude of oscillation, nor, possibly, of the rate of the general retreat, but mainly the influence of topography.

If the moraines showed nothing further it would seem clear that the rate of the main retreat had been perfectly uniform, or at least very nearly so. But if we turn to northern Michigan and compare the intervals of four moraines there with the four south of Fort Wayne, an increase of the interval northward seems to be suggested. South and southwest of Fort Wayne four parallel moraines (the sixth to the ninth) lie within a space

of forty-five miles. They were formed at the broad apex of the Maumee lobe expanding on a nearly level plain. In the north there are four parallel moraines (the twelfth to the fifteenth) also in a space of forty-five miles on a line running southwest from Rogers City past Gaylord. These moraines are banked up against the northeast face of the highlands and mark a great reëntrant angle of the ice-front. The fifteenth is 800 or 900 feet lower than the twelfth, while the ninth near Fort Wayne (on a line running southwest from Paulding, Ohio) is only about 100 feet below the sixth. At present we have no measure of the intervals in the north except on this steep slope. It seems plain, however, that if these four moraines had been laid down on a level plain without being banked up against the highlands the normal interval would have been considerably greater than it is. On the other hand, near Fort Wayne it seems clear that if the highlands of northeastern Ohio and western Pennsylvania and New York had been absent and a level plain there instead, so that the expansion could have been distributed evenly along the edge, the normal interval would have been somewhat less than it is.

These facts seem to show that while the oscillations were going on, probably at a substantially regular rate, the main climatic amelioration and its resulting glacial retreat was also going on, not uniformly, but at a progressively increasing rate. From the first (or second) moraine near Cincinnati, where the great advance of this epoch had stopped and the great retreat begun, the ice-front retreated at first very slowly, but faster and faster as the front receded northward. Here again the character of the simple harmonic motion seems to be revealed as the probable manner of the varying rate of retreat. And this gives a decidedly astronomical quality to the cause. Whether the cause was due to some greater variation like precession, or to some slow orbital change, either of eccentricity, or of magnitude affecting the distance of the earth from the sun independently of eccentricity, it may at least be said that any variation of climate that can be so represented must spring from a cause which

proceeds in a great curve, and if glacial epochs are periodic, as they may be, then the variation is expressed by a closed curve, either circular or elliptical.

The manner of retreat under such a combination of forces may be represented graphically with approximate accuracy as follows: Assuming the oscillation to be superposed upon a greater amelioration having a uniform rate, the resulting path would be an epicyclic curve. If the recession took the form of retreats and halts without readvances the curve would come to a point at the moraines as in Fig. 4, A, and the moraines would have cross sections, under the simplest conditions of formation, like that shown in the figure. With readvances the curve would be a looping epicycle as in Fig. 4, B, (*a*) and (*b*), and if the readvances covered more than half of each preceding space of retreat the loops would overlap as in Fig. 4, B, (*c*). In both free and overlapping loops, the forms of the moraines would be as shown in Fig. 1 at A, and in Fig. 4, B, and C. As we have seen, this last appears to have been the actual manner of retreat, at least in Ohio, Indiana, and Michigan. This is shown in Fig. 4, B, (*c*). If the greater climatic variation is truly represented by a simple harmonic motion, then the overlapping of the loops was most extensive near Cincinnati, and decreased going northward. This order of retreat is represented approximately by Fig. 4, C. The facts seem to favor this method of interpretation quite strongly, but it is not necessary to pursue the theoretical aspect of the problem further here. It is suggested in this paper that precession of the equinoxes may have been the cause of the secondary climatic oscillations which produced the moraines of recession. But no statement, nor even a definite opinion, is ventured as to the cause of the greater, primary variation of climate which brought on the Ice age itself, except that it was of an astronomical nature. It may be added, however, that the astronomical theory of Croll even as modified and reënforced by Ball, is thought not to afford an adequate or satisfactory explanation. As to those other various hypotheses which postulate purely terrestrial causes, such as the displacement of the

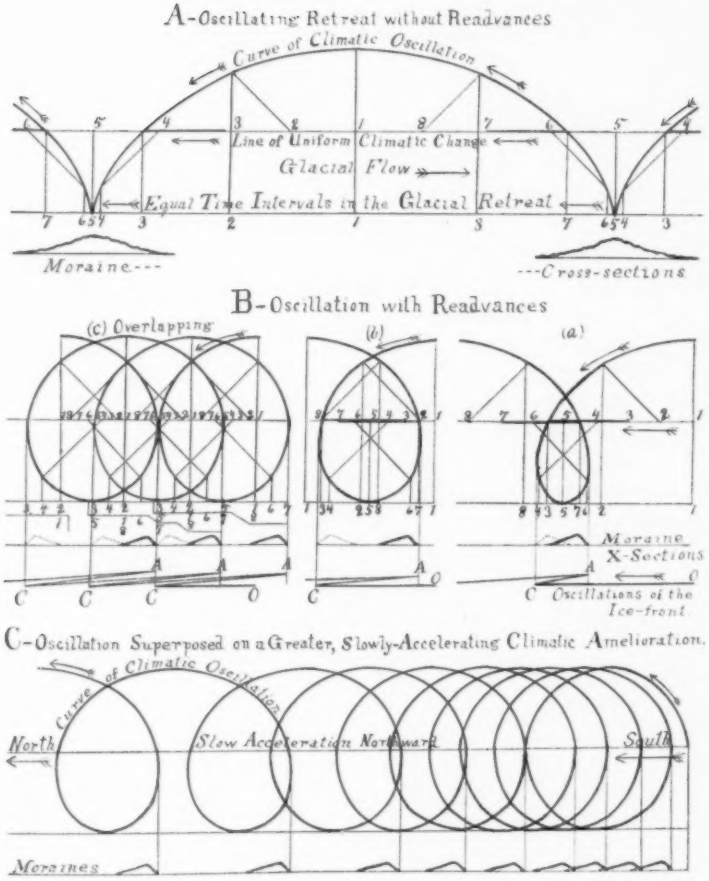


FIG. 4. Showing combinations of the period oscillation with the greater climatic change.

Gulf Stream by the submergence of the Isthmus of Panama or by the elevation of a supposed Antillean continent, or those that rely upon mere epeirogenic uplift in the north, they have no sort of intelligible relation to the characters revealed by the drift. In fact they appear to fall so far short of explaining these characters that there seems to be no longer a hope of gaining any real advantage from their consideration.

SUMMARY.

1. Between Cincinnati and Mackinac the Wisconsin drift formation has fifteen terminal moraines which form a consecutive series marking the retreat of the last ice-sheet; and there are three more farther north probably belonging to the same set. The series seems to be complete and is believed to constitute the simplest and most perfect known.

2. Making due allowance for the influence of topography, it appears that the intervals between the members of the series are remarkably regular, suggesting periodic halts or oscillations of the retreating ice-front, which appear to be attributable only to a periodic change of climate. But, excepting the annual period and a thirty-five-year period deduced by Forel and others from glacial and meteorological observations, the only periodic change of climate known is that due to the precession of the equinoxes with a period averaging 21,000 years and a minimum of 10,500.

3. A study of the forms of the moraines where they were made under the simplest conditions shows that they were always made at the climax of a readvance. In one instance at least the readvance appears to have covered more than half of the space of the previous retreat. Theoretically, the influence of precession on climate would cause a to and fro oscillation of the ice-front after the manner of a simple harmonic, and this superposed upon a greater and slower change, would produce an oscillating retreat with minor periodic readvances. This appears in fact to have been the manner of retreat during the formation of the moraine series, for those formed under the simplest con-

ditions have their crests forward; they have relatively short, steep front slopes and long gentle back slopes.

4. In attempting to deduce a period of oscillation from the study of existing things, the present ice-cap of Greenland was taken as the closest analogue for interpreting the drift of the Laurentide ice-sheet, and the chief reliance is placed in the observations of Professors Chamberlin and Salisbury. From these the conclusion is reached that the frontal edges of the great ice lobes that made the moraines of recession moved only very slowly, so slowly as to be in substantial accord with a period of oscillation equal to the minimum value of the precessional period. A period of between 5000 and 10,000 years, however, would seem to accord most closely with the phenomena. From Fort Wayne to Port Huron there are five moraines with four intervals of about fifty miles each. On this basis the Fort Wayne moraine with a width of five miles would have required something between 700 and 1600 years for its making.

5. The regularity of the oscillation and also of the greater climatic change upon which it was superposed both point clearly to astronomical causes. The periodic oscillation may have been due to precession, but no opinion is ventured as to the cause of the greater change. On this basis then, it took the ice-front 75,000 to 150,000 years to retreat from Cincinnati to Mackinac, and the whole glacial epoch lasted at least 150,000 years and possibly 300,000 or more. And if glacial epochs are periodic, as they may possibly be, then this period is only a fraction of the great cycle of climatic change.

FRANK BURSLEY TAYLOR.

THE ERUPTIVE ROCKS OF MEXICO.

PART III of the recently published *Bosquejo Geológico de México* consists of a study by Ezequiel Ordoñez of the eruptive rocks of Mexico.[1] This may be regarded as the most complete and satisfactory summary of the present state of knowledge of this subject which has yet been published.

Humboldt's *Essay on New Spain* contains many observations on the rocks of the silver-bearing regions of Mexico which are made with great accuracy and fullness of detail. But the science of petrography has made many advances since Humboldt's day. It is no longer sufficient to describe rocks as primitive schists and porphyries nor can altered andesites and tuffs be disposed of as graywackes. These terms are, however, an improvement on *saxum metalliferum*, the name by which many of the rocks were earlier known. Modern geologists, moreover, can hardly agree with the great *savant* in his conclusion that the richness of veins is entirely independent of the nature of the rocks which the veins traverse. The great similarity found among the rocks of the silver-bearing regions of Mexico and their resemblance to those of Nevada and Germany in which similar veins occur, indicates that a definite relation probably exists between rock and vein.

Humboldt's work, however, remains about the only authoritative one on the rocks of Mexico as a whole, which can be consulted. The names which he applied to the rocks and the opinions which he expressed regarding their origin will be found to be those prevailing in Mexico today. Since the publication of his work studies of single rocks or of limited regions have been published, but little, if any, attempt has been made to correlate observations. There is room, therefore, for a comprehensive study of the kind made by Señor Ordoñez.

[1] *Boletin del Institute Geológico de México*, Nums. 4, 5, y 6, Mexico, 1897.

In his paper the rocks are described in terms of modern petrography and with as much detail as the plan of the sketch permits. This plan he states to be an endeavor to give some idea of the petrographic provinces of the country, indicating for each one of them the predominating species, without entering into minute details concerning the extent of each. Commencing with the pre-Cretaceous rocks, the granites, pegmatites, granulites, syenites, and dicrites of this age are described in order in their respective provinces. The post-Cretaceous rocks are discussed next, beginning with the granites and passing on in order through the granulites, diorites, diabases, andesites, dacites and rhyolites. Then are taken up what are called the andesites of the second invasion, which were produced by the volcanic eruptions which began near the end of the Tertiary period. Finally the labradorites and basalts which largely characterize the latest eruptions are considered. Of especial interest is the account given of the rocks of the great silver-bearing regions of Zacatecas, Guanajuato and Pachuca, regions which though widely separated, the author finds to present remarkable uniformity as to kinds of rock and circumstances of outflow.

The work is marred by some errors, such as calling hypersthene a monoclinic pyroxene (p. 264), and the indiscriminate use of the terms amphibole and hornblende. The punctuation and paragraphing also admit of much improvement. The character of the work is as a whole, however, so admirable, that I have thought that to give a résumé of it by means of a translation of extracts would assure a wider circulation to some of the facts enunciated by Señor Ordoñez than they would perhaps otherwise attain. Of such extracts the remainder of this paper is made up.

The first indication of the part of the American continent which forms the country of Mexico, was given in Palæozoic time by the emergence of a narrow, elongated backbone which uniting with the beginnings of the Rocky Mountains to the north and of the Andes to the south constituted the foundation

of the orographic system known as the Cordillera of the Andes It is in the part of Mexico known by the name of the Western Sierra Madre that we may expect to find the principal types of ancient eruptive rocks, associated as a rule with crystalline schists and some of the earliest sedimentary rocks. The Sierra Madre extends along the Pacific coast in a general southeast-northwest direction. The western slopes, generally descending rapidly to the coast, present a notable contrast to those of the east, where numerous spurs or secondary sierras serve to support the extensive plateau of the Mesa Central. It was along the eastern slopes that the eruptive movements which in epochs later than the Cretaceous added to the relief of the Sierra Madre, chiefly occurred. Here may be seen the whole series of modern eruptive rocks, from the granites with which the eruptions clearly began, to the basalts of Quaternary time.

Considering first, then, the pre-Cretaceous rocks, we find them consisting chiefly of granites. These probably make up a large part of the mountains along the western coast of the Peninsula of Lower California, but of their exact distribution we know as yet little. In the region of Hermosillo, Sonora, in the district of Moctezuma, granite, crossed by dikes of pegmatite, occupies great tracts of country. In the district of Altar syenites and diorites replace the granite. In the region south of the state of Puebla in the districts of Chiautla and Matamoros micaceous or amphibolic granites are found passing over to gneiss or green schists. The granites are interrupted frequently by modern eruptive rocks, chiefly rhyolites and andesites, or even by stratified rocks, generally Cretaceous. In the state of Jalisco in the canton of Mascota and along the slopes of the Sierra toward the Pacific, the group of mountains of Desmoronado is formed of granites associated with quartzites and other metamorphic schists. In the central and western parts of the state of Oaxaca may be seen an extensive formation of granites and diorites, covered sometimes by breccias and modern quartzose conglomerates. These ancient masses, chiefly granites, may be followed, although interrupted by modern eruptive and sedi-

mentary rocks, nearly to the coast of the Pacific and the Isthmus of Tehauntepec.

By far the larger number of the eruptive rocks of Mexico are, however, of post-Cretaceous origin. Among the rocks which began this prolonged eruptive epoch, granites and granulites predominate, syenites are rare, andesitic diorites are abundant, and diabases sometimes occur. The different varieties, however, pass from one to another by insensible gradations, and frequently exhibit as well an ophitic or trachytic structure which leads them to resemble the true porphyrites and andesites. The frequent recurrence of these phenomena serves as a corroboration of Iddings' theory of the differentiation of magmas. The post-Cretaceous eruptive rocks which approximate in structure most nearly to those of pre-Cretaceous age, occur chiefly in the central regions of the northern and northeastern portions of the country, and are usually associated with Cretaceous limestones. The granulitic structure is that which predominates, but it may be modified to that of the granites, or even descend through the micro-granulites to the orthophyres and rhyolites.

The rocks which come after the granites have usually been known in Mexico as greenstones or green porphyries on account of their characteristic color and porphyritic appearance. To these rocks great interest has long been attached since they lodge the most important metalliferous veins of the country. A chart showing the mines of Mexico well indicates the distribution of these rocks. Each metalliferous district presents in the mass of its rocks a similar series of eruptions, thus indicating a certain contemporaneity and analogy of circumstances of outflow. The three types of rocks found in these districts in the order of their appearance are: (*a*) andesites and green dacites, (*b*) rhyolites, and (*c*) labradorites and basalts.

Those of the first type have already been referred to as greenstones. They may also be described as andesitic porphyrites, chiefly of hornblende, and orthophyres, while some more nearly resemble the amphibole and pyroxene-andesites. All present similarities to the rocks described by von Richthofen

under the general name of propylites, which are well known in Hungary, Transylvania, Nevada, and from some South American localities. They present various aspects of the trachytic and trachyto-porphyritic structure, a different quantity and development of the elements of the first generation sometimes causing the microlitic magma to predominate over the amorphous. An idea of the various aspects which these rocks present can be given by mentioning some from different localities. Commencing with the dacitic types, one may note the rock which occurs at various points in the mining district of Parral, in the state of Chihuahua. It is dark green to dull green in color, and contains scattered crystals of transparent feldspar, together with hornblende that to the naked eye appears to be of a dark green color, and lamellæ of dark green mica. The magma is of a character in part microfelsitic and in part microlitic, with disseminated particles of yellowish green hornblende, which is the mineral which gives to the rock its color. The crystals of hornblende are in part decomposed and do not always preserve their sections. This alteration, either central or peripheral, consists of a transformation to calcite, chlorite and sometimes to epidote.

To judge by the free quartz which it sometimes contains, this rock bears some similarity to the felso-dacites of propylitic appearance, of Rosenbusch, and may correspond in part to the dacites as well as to the porphyrites of Fouqué and Lévy that are likewise analogous to some of the propylites described by Zirkel from the Virginia Range. In the same region these rocks sometimes have a lighter color owing to the abundance of disseminated feldspar crystals which give a more marked porphyritic appearance. There may also be observed with the naked eye and in very variable quantity, grains of pyrite disseminated in the paste.

In the region of Guanacevi, Durango, altered andesites of green color form the rocks of the first eruption. With these are associated superposed andesitic tuffs and sometimes rhyolitic tuffs, likewise green, in beds of considerable thickness which

always contain veins of epidote visible in thin layers. The greater number of the mineral veins of this locality occur in these rocks. In the state of Sinaloa these greenstones abound in many of the mining districts, but are more or less altered by the contact of the metalliferous veins, now gold, now silver-bearing. These microlitic greenstones pass sometimes to an ophitic structure, and even to holocrystalline rocks of clearly granitic structure giving types of diorites and diabases. In the territory of Tepic green andesites occur in great quantity, always with analogous characters. In the state of Jalisco green dacites occur at the mines of Los Reyes, San Sebastian, and Real Alto.

In Fresnillo and Sombrerete, in the state of Zacatecas, rocks of similar aspect are found covered by an extensive formation of rhyolite tuffs.[1] In the district of La Luz, state of Guanajuato, the small size of the mineral elements and the profound alteration which the rocks have undergone prevents usually an exact microscopic determination of the minerals or the rock structures. It is, however, possible in some cases to observe characters which show that the rocks approximate to andesitic porphyrites or hornblende andesites.[2] It is interesting to note that there exist great similarities between the rocks of La Luz and those associated with the rhyolite tuffs in the mines of the state of Zacatecas. The fine grain of the former rock has indeed caused it to be called a rhyolite tuff.

As regards the age of the formations of La Luz and those about the city of Guanajuato, various conclusions have been reached, owing to the absence of fossil remains in the sediments, as well as the complex nature of the eruptive regions of the vicinity. The rocks of the latter regions, which include the hornblende granites of Santa Ana and the granites of the Ser-

[1] The rocks classified as rhyolite tuffs are some of them andesitic tuffs which appeared during the eruptions of andesites, and were later impregnated with silica, while others were derived from the eruptions of rhyolites.

[2] The term porphyrite is restricted in use by Ordoñez, but is employed by him to designate Tertiary rocks differing slightly in appearance from the common andesites and showing peculiar alteration.

rania del Gigante, belong undoubtedly to a pre-Cretaceous epoch. Fragments of these granites, syenites, etc., occur in the red conglomerate of Guanajuato. They are undoubtedly anterior to the rocks of La Luz, which may be considered to be recent Tertiary.

In the metalliferous regions of Pachuca, Real del Monte, and El Chico, in the state of Hidalgo, altered pyroxene-andesites and dacites of green, dark and light gray, and violet color, constitute the predominating eruptive rocks. They are distinguished from the rocks previously cited chiefly by their structure, which may be considered as invariably trachyto-porphyritic; a structure produced by large crystals of labradorite and altered remains of crystals of pyroxene. Andesite tuffs like those of Guanacevi or rhyolite tuffs like those of Zacatecas scarcely occur at all. There are many other points along the Sierra Madre where the andesitic greenstones occur, chiefly in the states of Chihuahua, Sinaloa, Durango, Jalisco, and the territory of Tepic. From these the regions of Zacatecas, Guanajuato, and Pachuca are somewhat distinct from an orographic point of view. Considered petrographically, however, they are mountain regions which, on account of the order of eruption of their igneous rocks, may be regarded as branches of the Sierra Madre penetrating toward the interior.

Trachytes and trachyte-andesites have in some of the localities mentioned immediately succeeded the andesites, either as a modification of the latter or as a later eruption. Trachytes are, however, relatively rare in Mexico, especially among the earlier eruptives. They are more frequent before the second period of andesites and in the modern eruptions.

The rhyolites appeared after the andesites, presenting the variations common to rocks of this type. They occur in many localities, only the principal ones of which can be indicated. In the central part of the Sierra Madre the rhyolites cover great areas. Here the structure passes from the micro-granulitic to one entirely vitreous giving obsidians and retinites. The rhyolites are likewise notably abundant in many places of the Mesa Cen-

tral, where some of them may be considered of later age than those of the Sierra Madre.

In general it can be said that the forms of the mountains of rhyolites are always characteristic, serving in many cases to foretell their nature, especially when this rock occurs alone in an extensive portion of one serrania. Of those with sharp and elongated peaks we have a good example in the peak of Bernal in the state of Queretaro. The extended forms present us great cliffs (*acantilados*) in the extensive serrania of Valdecanas and in the no less interesting Sierra Fria in the state of Zacatecas.

In the second of these serranias, formed in great part of rhyolites, variations of structure and texture have brought about the formation of plateaus and dome-like summits and erosion has given rise to broken, fantastic shapes. In this sierra as in many other localities formed of the same rock, the spherulitic rhyolites of slightly coherent or tufaceous paste alternate in beds more or less horizontal or parallel with petrosiliceous rhyolites charged with quartz, which are compact and resist the forces of erosion. The result is an appearance of steps or stairs at different heights on the slopes of the mountains. The surfaces of the separated blocks, as a result of contraction or atmospheric action, generally have columnar or other imitative forms, such as are shown by some of the peaks called The Friars; a name by which rocks of columnar structure are designated in various parts of the country.

As notably spherulitic rhyolites can be mentioned those of Chichindaro, in the state of Guanajuato, and those of San Ildefonso, Tula, Hidalgo. There are spherulitic and perlitic retinites in Apaseo el Alto, which are of pretty appearance on account of the contrast of color which the gray or black amorphous paste offers to the generally red spherulitic globules. But the most abundant rhyolites are the petro-siliceous rhyolites of various shades, red, black, violet, etc., such as those of the Sierra del Jaral and other points in the vicinity of the regions of San Luis Potosi, together with those of Guanajuato, Pozos, Peñoles, etc. Some of the latter frequently are accompanied

by retinites, which may come to predominate, as in the hill Xicuco between Tula and Mixquiahuala of the state of Hidalgo. The violet-colored rhyolites that occur in flows in the Tertiary formations of the Acacico near Yahualica, Jalisco, are notable for the curious forms (axiolites) which the microfelsitic paste presents under the microscope; forms very similar to those which Zirkel describes in a rock from the Black Rock Mountains, Nevada.

In the central part of the country between the parallels 19° and 21′ N. Lat., a notable eruptive zone exists. In this zone the appearance of modern eruptives has commenced generally with the rhyolites, to which have succeeded andesites of a second eruption, a lesser number of trachytes and the labradorites and basalts which form the chief eruptions of the modern volcanoes.

The andesites of the second epoch always present characters by which they can readily be distinguished from those of the first. The orthorhombic pyroxene, hypersthene occurs frequently among the ferro-magnesian elements of the rocks, now as a principal and now as an accessory constituent. The microlitic feature so marked in the earlier rocks diminishes little by little and the proportion of the amorphous groundmass, always devitrified, is increased.

A grouping of the andesites by regions, subdividing them by varieties of structure or the predominating ferro-megnsian element, is not practicable on account of the constant change which occurs in the nature of the component minerals and degree of crystallization. The hornblende-andesites of a microlitic and felsitic magma sometimes containing quartz (dacites) appear to have been erupted immediately after the rhyolites in the second andesitic period. The dacites are anterior to the pyroxene-andesites, likewise of the second epoch, as is shown by the frequently observed superposition of the latter and by the thick sedimentary deposits which have covered the dacites. Alluvium with pebbles of dacite is also found at great depths in the interior of several of the valleys. The hornblende-andesites

are distinguished as a general rule from the hornblende-andesites of theformer epoch by the exclusive existence of gray hornblende with strong dichroism, altered often in the periphery of the crystals into ferruginous products. The colors which generally predominate are grayish-violet and red. The latter color comes from the alteration of the violet by the decomposition of the crystals of amphibole into oxides of iron which are disseminated in the groundmass. The majority are of trachyto-porphyritic aspect.

Contemporaneous with or perhaps previous to these andesites should be noted the greater part of the hornblendic or micaceous trachytes whose number is, to be sure, limited, especially if compared with the number of those which were considered trachytes before the application of the microscope. The presence of hypersthene in abundance in andesites marks the end of the andesitic eruption, since such andesites are seen alternating with the basalts of modern outflows.

Hornblende-hypersthene-andesites are found in abundance in many places. Such are localities in the sierra which bounds the valley of Mexico on the west, in the valley of Toluca and in some parts of the Sierra Madre of the state of Chihuahua. The vitreous types of these rocks and some dacites frequently occur. These present a vitreous magma having spherulitic and perlitic structures. Andesitic obsidians with amphibole or mica are found in dikes as intrusives in the valley of Mexico.

Passing to the andesites made up wholly or chiefly of hypersthene, two varieties may be distinguished: first, those having a largely microlitic groundmass, and, second, those in which the amorphous groundmass predominates (andesitic obsidians). In many localities the two aspects of structure are associated and the fact that they grade into one another shows that the differences arise from variations in the conditions at the time of eruption.

In the andesitic-obsidians the augite appears successively in the first and second generations and then under a quasi-crystalline form, that is, as a simple devitrification of the amorphous

groundmass, or even in very small microlites. The andesitic eruptions of our volcanoes have produced these vitreous rocks charged with pyroxene. Such may be seen in the lavas of the volcano Colima and the early eruptions of Popocatepetl.

While andesites of the vitreous types predominate in the more recent eruptions, trachytes of the vitreous type also occur. The lavas of 1870 thrown from the volcano of Ceboruco furnish us a good example of this and may be designated as obsidian-like pyroxene-trachytes. Vitreous trachytes are likewise found in the volcanoes of Popocatepetl and Colima.

The presence of olivine as an accidental element in these rocks gives them to the naked eye the appearance of basalts. With these they have sometimes been confounded owing to the similarity of color and superficially blistered appearance, common to the basaltic lavas. There can be no doubt that they pass from one to another by insensible gradations since the diminution of oligoclase with the absolute predominance of labradorite, brings them to basic types represented by labradorites and basalts. Such gradations may be actually observed in some places in the valley of Mexico.

After the hornblende-andesites, which seem to have succeeded the rhyolites, the eruptions continued not only by emission of compact rocks, but also by an enormous quantity of broken products that were changed to sediments by watery vapors of the same eruptions and by atmospheric agencies Thus have originated those thick deposits of andesitic tuffs, breccias, etc., which are so abundant in different portions of the great central valleys of the country. The more superficial layers, having the lightness and fineness of detritus, have indeed been confounded at times with æolian products.

Lastly may be noted the labradorites, that is, basalts containing no, or only accidental, olivine, and the true basalts which occur in the volcanic regions or in rare cases rest upon or break through the Cretaceous limestones.

Labradorites occur in contact with the andesites of the first epoch and rhyolites, at various points along the eastern slopes of

the Sierra Madre. Among these points may be mentioned El Parral, in the state of Chihuahua; El Nayarit, in the territory of Tepic; the eastern part of the state of Jalisco; and near the volcano of Jorullo in the state of Michoacan. The early age of these labradorites is indicated by the fact that olivine is rare or absent. In the modern labradorites it occurs with more frequency.

These labradorites frequently exhibit a columnar structure, the most striking example of which is seen in the famous columns, 130 feet in length, along the Barranca of Regla in the state of Hidalgo. These stand upon Tertiary tuffs, resting in their turn upon arenaceous Upper Cretaceous limestones. The labradorites are compact, of gray color, and contain scattered grains of olivine. Geodes of zeolites occur in the columns, chabazite being most common, while thomsonite and arragonite are also found. The later series of labradorites and basalts continued up to the latest volcanic eruptions. Examples are found in the mountains about the valley of Mexico, as in the Peñon de los Baños, where pyroxene-labradorites in thin layers exhibit curious undulations. In some lava flows near the volcano of Ajusco at the southern part of the valley occur labradorites formed simply by a marked diminution of the olivine in the basalts which predominate in the region.

The vitreous hypersthene-andesites which formed the larger part of the early volcanic outflows were succeeded by basalts erupted through new volcanic foci. These exhibit an abundance of olivine in a microlitic groundmass of labradorite and pyroxene. The outflow of basalts in turn ceased, however, and the field was left anew to the hypersthene rocks which characterize the lavas of the volcanoes now in activity. This alternation is illustrated by contrasting the olivine-basalts of Jorullo of the middle of the last century with the present outflows of Ceboruco and Colima which present good types of trachytes and pyroxene-andesites with vitreous groundmasses.

In the northern region of the country, over the Mesa Central and along various points of the eastern Cordillera Madre,

basalts occur cutting their way through Mesozoic sediments and covering the Tertiary eruptives. In the plain extending to the south of the Cordillera of Mazapil and in the portion between the mountains of Gruñidora and Ahorcados, Tertiary basalts come up through the schistose Cretaceous limestones and along the upper surface of the latter marked metamorphism has been produced by the contact.

After the work of eroding waters had filled the valley of Mexico and made it habitable by man, a mighty cataclysm devastated the southern part of the valley. A flow of basalt ten miles in length, accompanied by showers of ashes, came from the volcano of Xitli and buried much of the inhabited region. Hence in the layers of pumiceous tuffs upon which these lavas rest, numerous utensils of primitive industry, human bones and bones of other modern vertebrates are found. The volcano of Toluca had ceased activity at this time, but Popocatapetl continued to pour forth eruptions of hypersthene-andesites. The eruptions of the latter volcano ceased at the beginning of this century, and now only a solfataric activity exists. The same is true of the Pico de Orizaba.

About the middle of the last century a new volcano appeared in the Mal Pais in the state of Michoacan. Its products were black basalts highly charged with olivine. With this last volcanic phenomenon was closed the prolonged inundation of basaltic and andesitic lavas which began to make itself felt at the end of the Tertiary period.

OLIVER C. FARRINGTON.

THE STRATIGRAPHY OF THE POTOMAC GROUP IN MARYLAND.[1]

CONTENTS.

Introduction.
Description of the deposits.
The Patuxent formation.
Name and areal distribution.
Leading features of the deposits.
Characteristic local sections.
Fossils.
The Arundel Formation.
Name and areal distribution.
Leading features of the deposits.
Characteristic local sections.
Fossils.
The Patapsco formation.
Name and areal distribution.
Leading features of the deposits.
Characteristic local sections.
Fossils.
The Raritan formation.
Name and areal distribution.
Leading features of the deposits.
Characteristic local sections.
Fossils.
Interpretation of the deposits.
Sedimentation and structural relations.
Correlation.
The Taxonomic views of other writers.
Comparative Taxonomic table.

INTRODUCTION.

The recent controversy regarding the age of the Potomac formation, which has been precipitated as the result of the conflicting evidence presented by the palæobotanists and the vertebrate palæontologists, suggests the necessity of determining the

[1] The investigations have been carried on under the auspices of the Maryland Geological Survey and the Woman's College of Baltimore.

sequence of the Potomac deposits, together with the horizons from which the fossils have been derived, if the questions at issue are to be finally settled. The authors of this paper have been engaged upon the investigation of these relations during the past year, and believe that much of the difference of opinion is due to the lack of knowledge regarding the stratigraphic position of the beds which have yielded the various plant and animal remains. They desire at the outset, however, to express their obligations to their predecessors in the field, without the results of whose work their own investigations would have been seriously retarded, if not rendered entirely abortive. The great volume of data which the palæobotanists have presented to us during the past few years, and the more meager evidence of the vertebrate palæontologists, have been of signal service in interpreting the stratigraphy of the Potomac formation. It is a pleasure to witness to the splendid achievements of Professors Ward, Fontaine, and Newberry, in the study of the fossil floras, and of Professor Marsh in extricating from poorly fossiliferous beds the important vertebrate remains which he states he has in store for us. The junior author of this paper has also made collections of the flora and fauna which will be discussed by him in a subsequent contribution.

The conclusions reached by those who have studied these two classes of organic remains may be briefly stated as follows: The palæobotanists, largely upon the discovery of dicotyledonous types of plant life, claim the Cretaceous age of the Potomac group, while Professor Marsh upon the evidence of the vertebrate remains, particularly of the Dinosauria, is as firmly convinced of the Jurassic age of the deposits.

It seems to the authors that the difficulty lies in the fact that each side has assumed too largely the unity of the Potomac group and has not sufficiently regarded the possibility of its representing more than a single formation. A marked exception to this is found in the late work of Professor Ward who has discovered several distinct stages in the fossil floras—a discrimination which is of much importance in determining the

stratigraphic relations of the higher portions of the Potomac deposits.

It is the conclusion of the authors, founded upon a detailed stratigraphic study of the Potomac group, that all the beds which have afforded dicotyledonous types of plant life are above those which have yielded the vertebrate remains, and, moreover, that a marked unconformity exists between the two series of deposits. The evidence for this conclusion will be brought out in the succeeding pages.

DESCRIPTION OF THE DEPOSITS.

The several formations into which the larger unit of the Potomac group has been divided are as follows:

Lower Cretaceous - -	(Raritan Formation) (Patapsco ")	Potomac
Upper Jurassic (?) - -	(Arundel ") (Patuxent ")	Group

THE PATUXENT FORMATION.

Name and areal distribution. — The Patuxent formation receives its name from the Patuxent River in the basin of which deposits of this horizon are found typically developed. As the basal member of the Potomac group the Patuxent formation occupies a position near the landward margin of the Coastal Plain, although the higher members of the series frequently overlap it and are found resting upon the crystalline rocks of the Piedmont Plateau to the westward. The Patuxent formation has been traced as a narrow, broken belt from Cecil county across Harford, Baltimore, Anne Arundel, and Prince George's counties to the borders of the District of Columbia.

Leading features of the deposits.— The deposits of the Patuxent formation consist mainly of sand, at times quite pure and gritty, but generally containing a considerable amount of kaolinized feldspar, producing a clearly defined arkose. Clay balls are at times distributed in considerable numbers through the arenaceous beds, which in places contain lenses of gravel, sometimes

with cobble stones. Frequently the sands pass over into sandy clays and these in turn into more highly argillaceous materials which are commonly of light color, but at times become lead-colored, brown or red, and not unlike the variegated clays of the Patapsco formation. Those arenaceous materials which lie adjacent to ferruginous clays are not infrequently indurated by hydrous oxides of iron, forming ferruginous sandstone. The more arenaceous deposits are commonly cross-bedded, and the whole formation gives evidence of rapid deposition.

The strike of the beds is in a general north-northeast south-southwest direction, corresponding to the eastern border of the Piedmont Plateau. The dip of the strata, so far as can be determined from the narrow exposures which have been obtained, is probably between thirty and forty feet to the mile. The irregular character of the sedimentation, together with the small areal extent of the deposits, renders it very difficult to make any satisfactory measurement.

The thickness of the Patuxent formation is rather variable, but, so far as has been determined, has not been found to exceed 150 feet, although it may be considerably thicker at some points.

Characteristic local sections.—The deposits of the Patuxent formation outcrop, among other places, in the valley of the Little and Big Patuxent rivers, having been reached in the iron-ore openings which have been made at many points in the overlying Arundel formation. An excellent section is found in a cutting on the Baltimore and Ohio Railroad a short distance to the south of Contee. At the latter locality the coarse gravelly phase of the formation is well developed, and is unconformably overlain by the iron-ore clays of the Arundel formation. At the southern end of the cut the gravels have become cemented near the contact with the Arundel into a considerable ledge of conglomerate, by the leaching into them of the hydrous oxide of iron from the overlying deposits.

One of the most comprehensive sections of the Patuxent formation is at School House Hill, Baltimore county, about three-quarters of a mile northwest of Lansdowne on the Baltimore and

Ohio Railroad, where a gulch, known as "Deep Ditch," on the southern side of the hill, has opened up one of the finest sections of the Potomac group. The Patuxent, Arundel, and Patapsco

FIG. 1. View at School House Hill, Baltimore County, showing Patuxent sands overlain by Arundel clays.

formations are all exposed at this locality. The section is as follows:

SECTION AT SCHOOL HOUSE HILL, BALTIMORE COUNTY.

Patapsco.	Argillaceous sands more or less iron-stained, with variegated clays, and with ferruginous crusts; ash-colored, lignitic and somewhat indurated toward the base; silicified coniferous and cycacean trunks. - - - - -	10 ft.
Arundel.	Slightly indurated, ferruginous ledge containing abundant impressions of monocotyledonous plants. - - -	1 ft.
	Drab-colored clays, with beds of lignite, containing "brown" and "white ore," exhibiting impressions of ferns; dinosaurian teeth; ferruginous ledge at base. - - -	50 ft.

Patuxent.	Compact, yellowish, reddish, and variegated sands, locally carbonaceous; brown clays containing flakes of iron ore (hydrous oxide); lead-colored clays with fragmentary plant remains; ferruginous ledge containing pipe ore. - -	30 ft
	Compact jointed clays of great variety of color, red, lilac, and white predominating; "paint rock" and lenses of coarse gravel containing balls of clay and silicified coniferous wood, passing into - - - - - - - -	20 ft
	Cross-bedded sand, slightly carbonaceous - - -	10 ft
	Total thickness, - - - - - -	121 ft

The slope of the hill is thickly covered with a wash composed of highly ferruginous sand charged with broken crusts of ironstone.

Another section of much interest is found near Federal Hill Baltimore city, where the Patuxent sands are apparently directly overlain by the Patapsco formation, lenses of the Arundel formation having been observed occurring in their proper stratigraphic position in the immediate vicinity. The section at Federal Hill, somewhat generalized, is as follows:

SECTION NEAR FEDERAL HILL, BALTIMORE CITY.

Raritan.	Sand and ferruginous sandstone containing silicified coniferous wood - - - - - - -	5 ft. 0 in
	Carbonaceous clays containing flakes of "white ore"	1 ft. 4 in
Patapsco.	Variegated clays with ironstone crusts - - -	34 ft. 6 in
	"Short" blue slickensides clay with logs of lignite and occasional fern impressions - - -	7 ft. 6 in.
	Fossiliferous "slaty clay," with ferns, cycads, conifers, monocotyledons and dicotyledons - - -	7 ft. 10 in.
	Indurated ferruginous layer containing "paint rock"	0 ft. 6 in.
Arundel.	Represented in immediate vicinity by lenses of lignitic clay with nodules of "white ore" and its derivatives - - - - - - - -	0 ft. 0 in
Patuxent.	White sand - - - - - - - -	7 ft. 0 in.
	Coarse sand with clay-balls - - - - -	4 ft. 0 in.
	White clay - - - - - - - -	5 ft. 0 in.
	Indurated gravel - - - - - - - -	4 ft. 0 in.
	Total thickness - - - - -	76 ft. 8 in.

Many other occurrences of the Patuxent formation might be cited both to the north and south of Baltimore, but enough have already been given to show its character and relations.

Fossils.—Very few traces of organic remains have as yet been found in the Patuxent formation. Those which have been obtained consist of lignetized coniferous wood, and various indeterminable vegetable fragments, among which no traces of dicotyledonous forms have been observed. A silicified coniferous trunk has been found *in situ* at School House Hill. One cycad trunk is also reported to have been seen in place in these beds. No animal remains have yet been with certainty detected.

THE ARUNDEL FORMATION.

Name and areal distribution.—The Arundel formation receives its name from Anne Arundel county where the deposits of this horizon are well developed. It has been traced as a broken belt all the way from Cecil county to the borders of the District of Columbia, and occurs as long narrow belts that extend in a general northwest-southeast direction forming a low angle with the border of the Piedmont Plateau.

Leading features of the deposits.—The deposits consist of a series of large and small lenses of iron ore-bearing clays which occupy ancient depressions in the surface of the Patuxent formation. These clays as most typically developed ("blue charcoal clays" of the miners) are drab colored, tough, and frequently highly carbonaceous, lignitized trunks of trees and limbs lying horizontally strongly compressed and frequently charged with or enclosed by carbonate and sulphide of iron. Sometimes these trunks are encountered in an upright position, with their larger roots still intact. Scattered through the dark clays are vast quantities of nodules of iron carbonate, at times reaching many tons in weight, and known to the miners as "white ore," "hone ore" or "steel ore." In the upper portions of the formation which have been exposed to atmospheric influences the carbonate ores have sometimes to considerable depth changed

to hydrous oxides of iron, which the miners recognize under the name of "brown" or "red" ore. Under these conditions also the originally drab-colored clays containing the carbonate

FIG. 2. Section at Reynold's Mine, Anne Arundel County, showing Arundel clays overlain by Patapsco formation.

ores have suffered a like chemical change, resulting in red or variegated clays. Where these clays chance to contain but little lignite the iron ore may consist almost entirely of these oxides.

The peculiar relations which the Arundel formation presents to the other members of the Potomac group render it difficult to say much regarding the strike and dip of the deposits, although the fact that they lie exposed in depressions upon the surface of the Patuxent formation renders it probable that these features do not differ materially from that observed in the other formations.

The lenses vary greatly in thickness, and from their character are at times lacking in portions of the country. The esti-

mates which were made of the thickness of the largest lenses observed render it probable that they attain at least 125 feet.

Characteristic local sections.— One of the best sections is found at Reynold's Mine on Piney Run, Anne Arundel county, one mile south of Hanover. It occurs on the western flank of the so-called "Elk Ridge" in a heavy lense constituting its axis and largely conditioning its existence. The section at Reynold's Mine is as follows:

SECTION AT REYNOLD'S MINE, ANNE ARUNDEL COUNTY.

Raritan.	White and light brown sand and gravel containing crusts of iron-stone	10 ft. 0 in.
Patapsco.	White, varigated argillaceous sands, "fuller's earth," clay and paint clay, with paint rock at the base; silicified coniferous and cycadean trunks.	10 ft. 0 in.
	Ferruginous ledge, more or less conglomeritic	0 ft. 3 in.
Arundel.	Drab colored compact laminated clays containing beds of lignite and bearing fern impressions; nodules, flakes and ledges of "white ore," slightly plant bearing	70+ ft.
	Total thickness	90 ft. 3 in.

Another important section is found at Muirkirk, Prince George's county, where also the iron ore clays have been extensively worked for many years. The Muirkirk section exposed at the "Old Blue Bank" on the Tyson estate is as follows:

SECTION OF "OLD BLUE BANK" MUIRKIRK, PRINCE GEORGE'S COUNTY.

Raritan.	Sandy gravel	4 ft.
Patapsco.	Mottled gravelly loam; silicified coniferous and cycadean trunks	12 ft.
Arundel.	Massive blue clay containing "white ore;" bones of Dinusauria at base	20 ft.
	Highly lignitic lens with "charcoal ore"	2 ft.
	Tough, "dry," blue clay with "white ore"	15 ft
Patuxent.	White sand	10+ ft.
	Total thickness	63 ft.

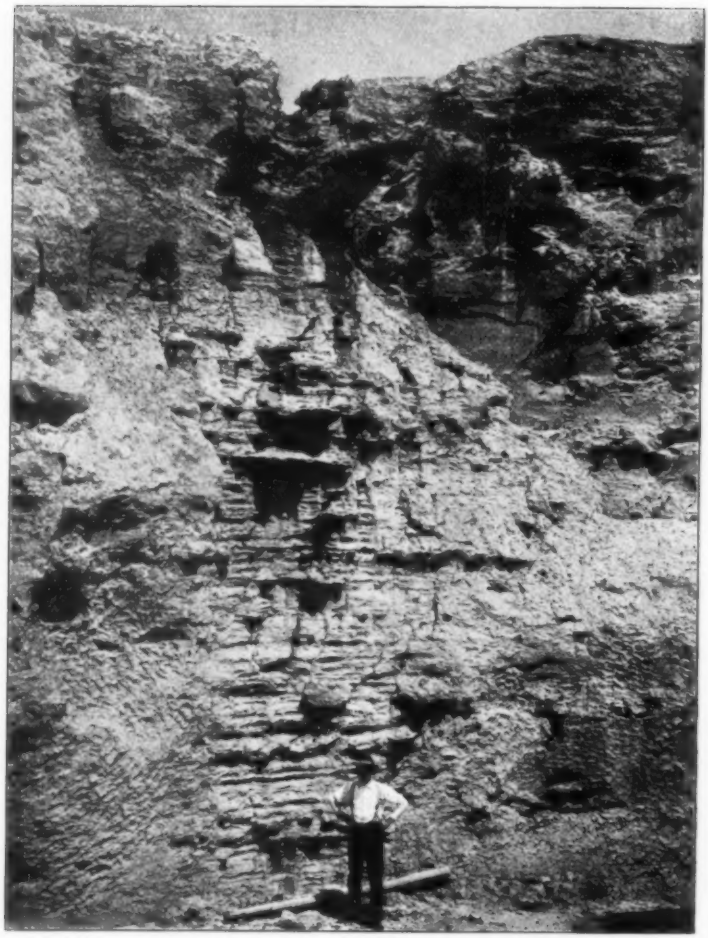


FIG. 3. Arundel formation showing nodules of "white ore" at Reynold's Mine, Anne Arundel County.

Many other characteristic local sections might be given, since the Arundel formation has been opened at numerous points for iron ore. Lenses have been observed among other places at the head of Elk River neck in Cecil county, in the vicinity of Joppa, Harford county, on Stemmers Run, Baltimore county, at Locust Point, Baltimore city, and at numerous localities in Anne Arundel and Prince George's counties.

Fossils.—Animal and plant remains have been observed at several localities in the Arundel formation. The Muirkirk area has afforded much the largest number. It was in this section that the vertebrate and cycadean remains of the Potomac group were first discovered by Mr. Philip T. Tyson. Later Professor O. C. Marsh of New Haven made extensive collections at this locality and upon this material based his conclusions regarding the age of the Potomac group. The vertebrate fossils consist largely of Dinosauria.

The plant fossils consist of ferns, conifers and monocotyledons. No dicotyledonous forms have yet been recognized.

THE PATAPSCO FORMATION.

Name and areal distribution.—The Patapsco formation is so called from its typical occurrence in the valley of the Patapsco River. It extends entirely across the state from the Delaware border to the Potomac River, and throughout this distance is one of the most important members of the Potomac group. It has a much larger areal extent than either of the two formations before described, and in places overlaps them, resting directly upon the crystalline rocks of the Piedmont Plateau.

Leading features of the deposits.—The deposits of the Patapsco formation consist chiefly of highly colored and variegated clays which grade over into lighter colored sands and clays, while sandy lenses of coarser materials are sometimes interstratified, which are occasionally indurated and at times form "pipe

ore." The clays are in places dark colored, massive and more or less lignitic. At times they are laminated ("slaty") and bear large numbers of leaf impressions. Fossiliferous flakes and nodules of "white" and "red ore" also occasionally occur. The sands sometimes contain much decomposed feldspar, and rounded lumps of clay are also found. The sands are frequently cross-bedded and give evidence of rapid deposition. Workable beds of "paint rock," as the highly ferruginous clays are termed, are found at many points, usually near the base of the formation.

The strike of the formation has a general north-northeast south-southwest direction, following the eastern margin of the Piedmont Plateau. The dip of the beds is somewhat less than that of the underlying formations, the deposits of the Patapsco formation transgressing the older strata, and as a result often come to lie directly upon the crystalline rocks to the westward.

A very marked unconformity is found between the deposits of the Patapsco and underlying formations. The thickness of the formation is estimated to reach fully 200 feet.

Characteristic local sections.— In addition to the several characteristic sections which have been already given, in which deposits of the Patapsco formation are found represented, the highly important locality of Cedar Hill in the area of Timber Neck in Anne Arundel county is also described. The section is on Licking Run one mile southwest of Hanover and is as follows:

SECTION AT CEDAR HILL, ANNE ARUNDEL COUNTY.

Raritan.	Reddish sands, somewhat gravelly, containing "pipe ore"	12 ft.
Patapsco.	White, red and brown sands, more or less argillaceous, containing clay pellets - - - - - -	20 ft.
Arundel.	Drab colored pyritous clays with beds of lignite; pellets, nodules and flakes of carbonate of iron ("white ore")	100 ft.
	White clay (in bed of Licking Run) - - - -	5 ft.
	Total thickness - - - - - -	137 ft.

Another interesting section is found on the opposite side of Licking Run in Reynold's "Spring Drain" mine, where the basal member of the Patapsco formation consists of a ledge of

FIG. 4. View of Timber Neck, Anne Arundel County, showing Arundel, Patapsco, and Raritan formations.

ferruginous conglomerate and is found lying unconformably upon the Arundel iron ore clays below. Innumerable sections of the Patapsco deposits are found in other mines and along the streams, railroads, and highways which cross this region.

Fossils.—The fossils which have been found in the Patapsco formation consist chiefly of plant remains. A few poorly preserved molluscan shells have been observed but no study has yet been given to them. No dinosaurian remains have yet been with certainty detected.

The plant remains consist mainly of ferns, cycads, conifers, monocotyledons and dicotyledons. The dicotyledonous forms are not uncommon and according to Professor Lester F. Ward

who has made a very exhaustive study of the flora from this horizon, represent among their number a few archaic types, while others approach quite closely to modern types of vegetation.

THE RARITAN FORMATION.

Name and areal distribution.—The Raritan formation receives its name from the Raritan Bay, New Jersey, where the deposits of this formation are typically developed. The name was given by the senior author of this paper in the annual report of the state geologist of New Jersey for 1892 although the term Raritan clays had been somewhat loosely used for deposits of this age by earlier writers.

The Raritan formation extends as a constantly narrowing belt from northern New Jersey into Maryland and disappears by the transgression of the upper Creteaceous formations near the borders of the District of Columbia.

Leading features of the deposits.—The deposits of the Raritan formation consist of sands and clays, the former largely predominating in the upper portion of the formation. The sands are frequently very pure and white but at times, especially in the lower portion of the formation are more or less colored and indurated by hydrous oxide of iron which produces the characteristic tube-like structure which is known as "pipe ore." The indurated beds are well exhibited at Rocky and Stony creeks on the south side of the Patapsco River, and at White Rocks in the immediate vicinity. The latter locality afforded the name of "Albirupean" which was applied by Professor Uhler to the upper portions of the Potomac group.

The clays are generally of very light color but at times become dark colored in the leaf-bearing zones. Beds of brown, black or earthy lignite, containing much pyrites, and occasionally amber (Cape Sable, Magothy River), have been observed at a few points. The clays are generally more or less arenaceous and grade over into the sandy deposits which largely characterize this formation.

The strike of the beds is in a generally north-northeast to south-southwest direction, corresponding to the Patapsco formation already described. The dip of the strata is probably

FIG. 5. Section of Raritan formation near Rocky Point above Round Bay, Severn River, Anne Arundel County, showing hard sandstone ledges at the right and white cross-bedded sands in the center.

slightly less than that of the underlying formation, and a slight transgression is noticeable to the northward.

The thickness of the Raritan formation in central Maryland is probably not far from 500 feet. It declines in thickness gradually to the southward where it finally disappears near the limits of the District of Columbia.

Characteristic local sections.—Very characteristic sections of the Raritan formation are shown in the bluffs of the Severn River in the vicinity and about Round Bay. On Rocky Point just above Round Bay an excellent exposure of the Raritan sands with the interbedded clays is exhibited, with a capping

of marine Cretaceous. The section at this point is as follows:

ROCKY POINT, ROUND BAY, SEVERN RIVER.

Matawan.	Black laminated sands highly weathered, producing a reddish and grayish motted appearance	10 ft.
Raritan.	Coarse, gritty sands with lenses of clay; the sand cross-bedded and often indurated, forming heavy ledges of ironstone	30 ft.
	Total thickness	40 ft.

Other excellent sections are seen on the Magothy River, on the Lower Patapsco and its tributaries, on Elk Neck, and near the mouth of the Sassafras River, in which very much the same characters are exhibited. The light colored sands are especially well developed on Elk Neck where they attain a very great thickness.

Fossils.—The fossils of the Raritan formation consist mainly of plant remains. Several brackish water molluscan shells have been obtained from the Raritan formation, farther to the north in New Jersey and it is not improbable that the same may be observed in Maryland when the deposits have been further studied. The fossil plants include dicotyledons of much more recent affinities than those of the Patapsco formation, the break between the two floras being very marked.

INTERPRETATION OF THE DEPOSITS.

The interpretation of the Potomac group involves the consideration of the sedimentation and structural relations of the deposits as well as of the entombed fossils, and each has an important bearing in the elucidation of the other. The conditions of sedimentation explain in no small degree the character of the fauna and flora while their features likewise throw light upon the physical conditions which existed during Potomac time.

Sedimentation and structural relations.—The sedimentation of this period can best be understood after an examination of

the physical conditions which prevailed during the time immediately preceding the opening of Potomac deposition. The results of recent work in the study of the physiography of the North

FIG. 6. Section below Round Bay, Anne Arundel County, showing Raritan formation overlain by Matawan formation.

American continent during the Mesozoic show that the eastern side of the country had been largely base-leveled, so that a long period of rock disintegration preceded the Potomac. With the advent of this period the land was tilted southeastward, and the increasing erosion brought about by this movement afforded the deposits of the Potomac group. That this movement was not continuous or persistent in the same direction is evidenced by the varying character of the deposits which have been already described. With the close of Potomac sedimentation a gradual transgression of the later marine formations across the margin

of the Potomac group took place, by means of which the higher strata were gradually cut off to the southward. The details of this transgression will be further explained in the subsequent pages.

The basal deposits of the Potomac group, which have been described under the name of the Patuxent formation, indicate in their arkosic character, their proximity to the ancient continent, the rocks of which had suffered extensive disintegration. These features so pronounced where the deposits lie adjoining gneissic or granitic rocks largely disappear where these rocks are poorly developed and where the deposits themselves were evidently laid down at some distance from the old shore line. Rapid deposition in shallow waters is seen in the cross-bedded character of the strata and their rapid change in character The appearance of clay balls, so widely disseminated at certain points, as above described, indicates the shallowing of the seas and the breaking down of pre-existing clay beds by wave action and the incorporation of the rolled materials by the later deposits.

The close of the Patuxent epoch was evidently marked by a gradual elevation of the deposits and the trenching of the surface by streams, so that a series of broad, shallow valleys was formed While this was going forward, a landward depression of the continent border evidently took place, producing series of long marshes in the ancient valleys, in which sedimentation was slow and in which swamp vegetation flourished. The tough clays, filled with lignitic accumulation, in which the tree trunks are sometimes found erect, with their roots still intact, can hardly find a satisfactory explanation upon any other basis. It was in these ancient marshes that the iron was deposited. It is also probable that some connection existed between these marshes and the area of basic eruptive rocks of central and northern Maryland. It was in these marshes that the bones of Dinosauria became entombed which, with the evidences of dense vegetation, suggests a sub-tropical climate.

The marked line of unconformity separating the Patapsco

formation from the two basal members of the Potomac group points to elevation after the close of the Arundel epoch and to a prolonged period of denudation. A striking feature of this erosion is the greater resistance which the Arundel clays presented when compared with the deposits of the Patuxent formation. The partially eroded clay lenses which project above the common line of contact can readily be explained upon these grounds. It was over this uneven surface that the deposits of the Patapsco formation were spread, reaching far beyond their western limits until they rested directly upon the crystalline rocks of the Piedmont Plateau. Their materials, so largely arkosic in the vicinity of the feldspathic rocks (gneiss and granite), point to the rapid stripping off of the disintegrated surface materials, and their deposition along the continent border. To how large an extent subsequent disintegration has kaolinized these materials it is difficult to determine, but that they had been extensively weathered prior to their removal seems justified. The highly colored and variegated clays which were evidently formed in the quieter and deeper waters of the Patapsco epoch bear some relation to the great belts of basic eruptive rocks which lie to the west and north of them. This phase of sedimentation is much more marked in central Maryland where the rocks of this character are most highly developed and where the proximity to the eastern margin of the Piedmont belt is most apparent. It is also probable that these highly colored clays were in part derived from the weathered surface of the Arundel iron-ore beds.

The unconformity separating the Raritan from the underlying deposits is less prominent than that which has been above described at the base of the Patapsco formation, although the gradual thinning of the Patapsco along its western margin and the overlapping of the Raritan points strongly toward a structural break. The Raritan deposits also obliquely transgress the other materials of the Potomac group northward until in the Delaware valley they come to rest directly upon the crystalline rocks of the Piedmont belt. The thick deposits of sand and

clay indicate rapid deposition in shallow waters and the general continuity of the beds points to wider and deeper water areas. The close of Raritan sedimentation by the depression of the continent border and the gradual transgression of the deposits of the marine Cretaceous southward is a phenomenon of unusual interest.

The line of unconformity which separates the Potomac group from the later Cretaceous formations is so poorly defined in local sections that absolute unconformity could hardly be proved except by the evidence of this gradual southward transgression which finally cuts off the entire Raritan formation on the banks of the Potomac River.

This review of the conditions of sedimentation during the Potomac period and of the relations which the individual formations hold to one another and to the rocks above and below them points to the probability of the existence of extended areas of fresh and brackish waters along the eastern border of the North American continent during Potomac time. Just how these conditions could have been produced in all instances is not clear and speculation regarding them seems hardly warranted by the facts which are at present before us.

Correlation.— The correlation of the formations composing the Potomac group must rest largely upon the fossils which have been derived from them, although the physical history of the continent renders it possible to establish certain broad comparisons along the Atlantic and Gulf borders that are not without their value. The similarity of conditions during the deposition of the Tuscaloosa beds in the south is clearly indicated, and the corroborative evidence which palæontology affords in this connection will be presently mentioned.

As was stated in the introduction to this article the tendency of most authors hitherto has been to regard the Potomac group as a single stratigraphic unit and the discovery of fossils of known affinities within its beds to be conclusive evidence of the age of the entire series of strata. From what has been said in the preceding chapters it is evident that the Potomac group is made

up of a series of formations, containing clearly defined faunas and floras, and separated by marked structural breaks at various points. It is necessary, therefore, to correlate each division of the group upon its own merits, and not upon the floral or faunal relations of the underlying and overlying formations.

The absence of knowledge regarding the character of the organic remains entombed in the Patuxent formation renders it impossible to speak with definiteness regarding the age of this division. Its position beneath the Arundel beds and the physi cal relations which it holds to this formation render it probable that they must both be assigned to approximately the same position in the geological time scale. The Arundel formation has afforded a number of vertebrate forms, largely Dinosauria, which Professor Marsh regards as indisputable proof of the Jurassic age of the deposits. The fossil plants which have been hitherto found in this formation are altogether in harmony with this view. No dicotyledonous types have been observed, while the ferns, conifers and monocotyledons could, so far as at present known, be as well referred to the Jurassic as to a later horizon. The evidence afforded by the vertebrate fossils is unfortunately incomplete as but few forms have as yet been figured and described, although Professor Marsh states that he possesses a large amount of unpublished material which fully corroborates the views which he has promulgated regarding the age of these beds. Professor Marsh admits the equivalence of these beds with portions at least of the Wealden formation of Europe which most authorities refer to the Cretaceous. The final interpretation of the vertebrate fauna evidently involves, therefore, the determination of the upper limits of the Jurassic itself rather than the correlation of the Potomac group simply, and this article is hardly the place to discuss the merits of so broad a question. It is not impossible, however, that portions of the Potomac as well as the Wealden may antedate the oldest known marine Cretaceous, and for that reason as well as on account of the distinguished authority of Professor Marsh the Patuxent and Arundel formations are provisionally referred by the authors to the Jurassic. The discov-

ery of vertebrate remains of Jurassic affinities in these formations is not, however, sufficient grounds for the reference of the entire Potomac group to the Jurassic period.

The Patapsco formation has afforded a rich flora in which dicotyledonous types are not uncommon. The fact that dicotyledonous forms have never been found elsewhere in rocks earlier than the Cretaceous is strong presumptive evidence of the Cretaceous age of these deposits; at the same time the fact that many other forms are identical or closely related to those of European horizons, generally referred to the Cretaceous, further substantiates this view. It is the opinion of Professor Ward, who has exhaustively studied the flora of this formation, that it is equivalent to the lower divisions of the Lower Cretaceous of Europe. Professor Ward has divided what the authors here recognize as a single stratigraphic unit into several zones, each with its characteristic plant forms, which, he states, give evidence of constantly progressive types in passing from the lowest to the highest members of the series. Whether these different zones represent a sequence of floras, or to a considerable extent local aggregations of forms under different physical conditions but of equivalent age, the authors are unable to determine, although they strongly incline to the latter view. The abundance of vegetation having a prominent cycadean element suggests a repetition of the mild climatic conditions which prevailed during the Arundel deposition.

The fossils of the Raritan formation are in the main distinct from those of the Patapsco and include a large assemblage of dicotyledonous types with much more modern affinities. Similar forms are found in the Tuscaloosa beds of the south, and it is the belief of Professor Ward that these deposits represent the Raritan formation in the north. The Raritan beds show strong floral affinities with the upper portions of the lower Cretaceous of Europe (Albian), and, according to Professor Ward, it is not impossible that the higher members of this formation to the north of New Jersey may even represent the basal portions of the upper Cretaceous as well (Cenomanian).

The Patapsco and Raritan formations have afforded no animal remains which are of determinative value; the fossil plants all point strongly to the lower Cretaceous age of the beds. So large an amount of evidence has been brought forward in support of this view by Professors Ward, Fontaine and Newberry, that the authors have no hesitancy in accepting their conclusions, and these two formations are therefore placed in the Cretaceous.

THE TAXONOMIC VIEWS OF OTHER WRITERS.

The earlier writers did not differentiate the Mesozoic deposits of the middle Atlantic slope into independent formations. For many years the basal clays and sands, which border the crystalline rocks of the Piedmont Plateau on the east, were considered the eastern equivalent of the red sandstones and shales with their enclosed coals farther west.

Professor W. B. Rogers, state geologist of Virginia, first sharply differentiated the eastern deposits from the western, and described the former under the name of the "Upper Secondary"[1] in his state report. In later articles Professor Rogers refers these deposits "at least in part to the horizon of the Upper Jurassic. Possibly we may find here a passage group analogous to the Wealden of British Geology."[2] On his geological map of the Virginias, and in his more recent publications, the deposits of the Potomac group are referred to as the "Jurasso-Cretaceous."

In the reports of Professor J. T. Ducatel, who was state geologist of Maryland between the years 1834 and 1841, comparatively little attention was given to the clays and sands at the base of the Coastal Plain series, and neither their stratigraphic nor taxonomic position was clearly defined. The reëstablishment of official geological work in Maryland by Philip T. Tyson,[3] who, as state agricultural chemist, published

[1] Geology of the Virginias. Report of 1840, p. 438.

[2] Geology of the Virginias, p. 712.

[3] First Rept. State. Agri. Chem., 1860, pp. 41–43.

his first report in 1860, led to a much fuller description of the Potomac deposits. He recognized two divisions in these basal strata, although his descriptions do not make it altogether clear that he understood their stratigraphic relations. He, however, differentiated the "Iron-ore Clays" which he described and mapped as distinct from another member composed of variegated materials ("a thick group of sands and clays of various colors"). He stated that this latter member in places abounded in lignite derived from coniferous plants, and in places contained beds of ferruginous sandstone. These deposits were referred with the sandy clays and greensand above them to the Cretaceous or Upper Secondary. In his second report, published in 1862, he referred the "Iron-ore Clays," on the supposed occurrence of fossil cycads in the beds, to the "Oolitic period."

In the "Memoir of the Geological Survey of Delaware,"[1] published by Professor J. C. Booth, the state geologist of Delaware, in 1841, the deposits which we are now considering were denominated the "Red Clay formation," and together with the "Greensand formation" above them classed as "Upper Secondary Deposits."

Professor H. D. Rogers, who published reports upon the geology of New Jersey in 1836 and 1840, described the deposits of that region as "Clays and Sands" without clearly defining their stratigraphic relations. Upon the organization of the second Geological Survey of New Jersey in 1854 under the direction of Wm. Kitchell, Professor George H. Cook began his extended investigations of the Coastal Plain series of that state. At a later period, as state geologist, he elaborated and classified these deposits in a manner that for many years met with wide acceptance. This classification is given in much detail in the *Geology of New Jersey* published in 1868.[2] The lowest of these formations is described by Professor Cook under the name of "Plastic Clays" and referred by him to the Cretaceous.

Little further attempt was made at the investigation of the

[1] Mem. Geol. Surv. Del., pp. 38–43.

[2] Geology of New Jersey 1868, pp. 249–257.

Potomac deposits until almost within the last decade. In 1885 Professor R. P. Whitfield, as the result of several years' study, published an important monograph upon "The Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey," in which several Lamellibranchs from the "Plastic Clays" of Professor Cook are described. While the investigations leading up to Professor Whitfield's report were in progress Professor William M. Fontaine, of the University of Virginia, began his elaborate study of the Mesozoic flora of Virginia. The published account of this work, however, did not appear until after the important stratigraphic study of Professor W J McGee, of the United States Geological Survey, which began a few years subsequently.

The investigations of Professor McGee upon the Potomac deposits were seriously commenced in the summer of 1885, and were participated in by Professor L. F. Ward, of the United States Geological Survey, and these gentlemen also coöperated soon after with Professor Fontaine. Some preliminary work had already been done by Professor McGee[1] in the previous year and the name "Potomac formation" proposed. Professor McGee continued his investigations of the Potomac formation during several years, and published a number of important papers regarding its stratigraphic features, the most comprehensive of these being entitled "Three Formations of the Middle Atlantic Slope."[2]

During this same period Professor P. R. Uhler,[3] of Baltimore, investigated the relations of the Potomac deposits in the Patapsco basin of central Maryland and proposed the division of these basal deposits into a lower member which he called the "Baltimorean," and an upper member which was designated the "Albirupean." In later publications[4] the term Potomac was accepted as the equivalent of the Baltimorean, and the "Alter-

[1] Rept. Health Officer, Dist. Columbia 1884–5 (1886), p. 20.

[2] Amer. Jour. Sci., 3d ser. Vol. XXXV, 1888, pp. 120–143.

[3] Proc. Amer. Phil. Soc., Vol. XXV, 1888, pp. 42–53.

[4] Md. Acad. Sci., Vol. I, 1892, pp. 185–202.

nate Clay Sands" placed at the top of the group as part of the Albirupean.

The senior author of this paper, in a study of the Coastal Plain formations of New Jersey, proposed in 1892 the name "Raritan formation"[1] for the "Plastic Clays" of Professor Cook, the term Raritan having been somewhat loosely used by several authors in earlier years in speaking of the clay deposits of this formation.

Mr. N. H. Darton,[2] of the United States Geological Survey, as a result of his study of the Coastal Plain in southern Maryland, differentiated a part of the sands at the top of the Potomac group as the "Magothy formation," which he considered might be equivalent to Professor Uhler's "Alternate Clay Sands."

The elaborate investigations of Professor Ward, which began as already described in 1885, have been continued to the present day. His exhaustive researches upon the fossil plants in the Potomac group have added largely to our knowledge of that formation. His most important publication[3] appeared in 1895, in which the Potomac formation is subdivided into a number of series, viz.:—

Albirupean Series,	Newer Potomac.
Iron Ore "	Older Potomac.
Aquia Creek "	
Mt. Vernon "	
Rappahannock Series,	
James River "	

The interest aroused in the age of the Potomac formation led to the collection by Mr. J. B. Hatcher under the direction of Professor O. C. Marsh[4] of the United States Geological Survey of vertebrate remains from the iron ore beds in the vicinity of Muirkirk, Prince George's county, Maryland. Upon the basis of these remains Professor Marsh has unequivocally referred the Potomac group of Maryland to the Jurassic. He has sub-

[1] Ann. Rept. State Geol., N. J., 1892 (1893), pp. 181–186.

[2] Amer. Jour. Sci., 3d ser., Vol. XLV, 1893, pp. 407–419.

[3] 15th Ann. Rept. Dir. U. S. Geol. Survey 1893–4 (1895), pp. 307–397.

[4] Amer. Jour. Sci., 3d ser., Vol. XXXI, 1888, pp. 89–97.

COMPARATIVE TAONGMIC TABLE.

		W. B. Rogers (state report)	W. B. Rogeers (later)	J. C. Booth	P. T. Tyson	G. H. Cook	R. P. Whitfield	J. S. Newberry	W. J. McGee	W. M. Fontaine	P. R. Uhler	N. H. Darton	O. C. Marsh	L. F. Ward
Cretaceous	Raritan	?	?		?	Plastic clays	Raritan clays	Amboy clays	?	?	Alternate clay sands	Magothy		Albirupean series
Cretaceous	Patapsco	Upper Secondary	Jurasso-Cretaceous	Red clay Formation (upper secondary)	Variegated clays and sands				Potomac	Potomac or Younger Mesozoic	Albirupean		Potomac (Jurassic)	Iron ore series Aquia Creek series Mt. Vernon series Rappahannock series James River series ?
Cretaceous	Arundel										Potomac or Baltimorean	Potomac		
Jurassic?	Patuxent				Iron ore clays									
		?		?										
					?									

sequently placed all of the Coastal Plain deposits beneath the marine Cretaceous in the same geologic division.[1] Professor Marsh claims the more recent discovery of a large amount of vertebrate material which throws much light upon the age of the Potomac formation and which he proposes shortly to describe. The last contribution of Professor Marsh brought about an extended discussion regarding the age of the Potomac group which was participated in by Messrs. Gilbert,[2] Marcou,[3] Hollick, Hill,[4] and Ward.[5]

The important postumous work of Professor J. S. Newberry entitled "The Flora of the Amboy Clays"[6] is a valuable contribution to the geology of the New Jersey portion of the Raritan formation. This work, which was edited by Arthur Hollick, represents the results of many years of investigation on the part of the late Professor Newberry.

The conclusions of the authors of this paper, as set forth in the preceding pages, are formed upon an extensive study of the Potomac group both in Maryland and New Jersey, and are seen to be quite different from those advanced by their predecessors. The comparative table on page 505 exhibits in a graphic manner the taxonomy of the several writers referred to, as interpreted by the authors of this paper.

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[1] Jurassic Formation of the Atlantic Coast, Amer. Jour. Sci., 4th ser., Vol. II, 1896, pp. 433–447; Science, n. ser., Vol. IV, pp. 805–816.

[2] Science, n. ser., Vol. IV, 1896, pp. 875–877.

[3] *Ibid.*, pp. 945–947; Vol. V, n. ser., 1897, pp. 149–152.

[4] *Ibid.*, pp. 918–922.

[5] *Ibid*, 1897, pp. 411–423.

[6] Monographs U. S. Geol. Surv., Vol. XXVI, Washington, 1895.

STUDIES FOR STUDENTS.

COMPARATIVE STUDY OF PALÆONTOGENY AND PHYLOGENY.

CONTENTS.

Introduction.
Law of acceleration of development.
Nomenclature of stages of growth.
Palæontogeny.
- Groups available.
- Brachiopoda.
- Crustacea.
- Mollusca.
- Pelecypoda.
- Cephalopoda.
- Method of working.

INTRODUCTION.

PALÆONTOLOGY ought to be synonymous with phylogeny, and biology with ontogenetic study; but when most palæontologists are content to describe species from a few characteristics of adults, and to guess at their relationships and history, and when many zoölogists are satisfied with basing species on color or some other minor mark, while the life history of even most living forms is wholly unknown, the need of higher ideals is evident.

All modern classification is intended to be genetic and is based on comparison of a series of adults from successive ages of the earth, of which the present time is but an episode. Interesting and valuable investigations in phylogeny have been made in this way, but such genealogies cannot, as a matter of course, be more than approximate, for the geologic record itself is incomplete, and the life record still more fragmentary. We

have nowhere a uniform succession of rocks, and nowhere an unbroken genetic series. It has been shown how often the facies of the Pacific coast[1] region has changed, and how it now belonged to one faunal region, and now to another, each great change in faunal geography showing some physiographic revolution here or elsewhere. Thus the local series is broken and filled in from other regions, species being classed together because of resemblance, while their real relationship is unknown.

LAW OF ACCELERATION OF DEVELOPMENT.

Since the geologic record is so badly broken, and since modern faunas and floras are but the topmost branches of a tree whose stock is only partly known, naturalists were merely groping in the dark in their efforts to get a genetic classification. There was however a glimmer of light, although scarcely heeded. No one man seems to have been the discoverer of the law of acceleration of development, but like the idea of evolution, it was in the air, and disclosed itself in various ways to the prophetic vision of seekers after truth. J. F. Meckel,[2] a German naturalist, seems to have been the first to give scientific expression to the biogenetic law, in his formula, "Gleichung zwischen der Entwicklung des Embryo und der Thierreihe," *comparison of development of the embryo with the race of animals.* But Louis Agassiz, although not the discoverer, was undoubtedly the first to use the law as an aid in the systematic study of biology. While he regarded the various genera, not as ancestors and descendants, but as progressive steps in creation, still he saw the analogy between the stages of growth of the individual and these progressive steps. It was reserved for Alpheus Hyatt to formulate the law, and to strengthen theory with practical examples based on study of Cephalopoda.[3] In his later papers Professor

[1] Jour. Geol., Vol. III, May–June 1895, Mesozoic Changes in the Faunal Geography of California. J. P. Smith.

[2] Syst. Vergl. Anat., I., Theil Halle, 1821.

[3] A. Hyatt, Mem. Boston Soc. Nat. Hist., Vol. I, 1866–7, and Proc. Boston Soc. Nat. Hist., Vol. I, 1866, "Parallelisms of Individual and Order among the Tetrabranchiate Mollusks."

Hyatt has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic, or are crowded out of the organization, and replaced in the development by characteristics of later origin."[1] A still more definite statement by the same author is the following: "The sub-stages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch or last embryonic stage."[2] Since Hyatt's first paper the law has been rediscovered and renamed by Haeckel,[3] "das biogenetische Grundgesetz" and by Würtenberger.[4] But these naturalists, instead of adding anything to Hyatt's definition, have failed to reach its clearness and simplicity. The only real addition that has been made is Cope's[5] idea of retardation, by which is explained the separation in the ontogeny of the descendant of characters that occurred simultaneously in the ancestor. Cope says: "The *acceleration* in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of *inexact parallelism.* As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has no doubt followed

[1] A. HYATT, Smithsonian Contributions to Knowledge, No. 673, "Genesis of the Arietidæ," Preface, p. ix.

[2] Proc. Am. Phil. Soc., Vol. XXXII, No. 143, A. HYATT, "Phylogeny of an Acquired Characteristic," p. 405.

[3] "Morphologie der Organismen," Vol. II; and "Anthropogenie," 1874.

[4] Ausland, 1873, and "Studien über die Stammesgeschichte der Ammoniten," 1880.

[5] Origin of the Fittest.

a law the reverse of acceleration, which has been called *retardation*. By the increasing slowness of the growth of the individuals of a genus, and later and later assumption of the characters of the latter, they would be successively lost."[1]

By a proper application of the law of acceleration as defined by Hyatt, and modified by Cope, all the facts of biology may be explained; there is no such thing as "falsification of the record." But as yet the law has had no great effect in classification, for most palæontologists have not approached their work from the biologic side, and biologists have been equally neglectful of the results attained by palæontology. A distinguished zoölogist once said to the writer, on being shown an ontogenetic series of ammonites, and the conclusions reached, "It is all beautiful, but almost too good to be true." In palæontology it is especially true that a naturalist may be a specialist in the fauna of one age, and know little of that of another. Hence the animals of various periods have been classified according to varying standards, all artificial. The only cure for these discrepancies is study of ontogeny, and comparison of stages of growth of the individual with ancestral genera. This will also prevent the description of supposedly new genera and species based on immature specimens, as has so often been done. The writer remembers once collecting numerous *Ceratites* in the Karnic limestone of the California Trias, much to his astonishment, for they ought not to occur so high up. He afterwards found, however, that they were not adults, but adolescent ceratitic stages of *Arpadites;* a similar case was the finding in the same horizon a *Tirolites* above its proper range, but it turned out to be the young of a *Trachyceras* that persisted unusually long in the *Tirolites* stage. At that time there was nothing in the description of these genera or any of their species to guide one, and so their ontogeny had to be worked out independently. But there is nothing in the description of almost any fossil genera and species to prevent just such mistakes, and they are constantly being made.

By careful study of ontogeny in comparison with phylogeny

[1] Origin of the Fittest, p. 142.

the palæontologist can correlate correctly fossil beds where even all the genera and species are new; he can even prophesy concerning the occurrence of *unknown* genera in certain horizons when he finds their minute counterparts in youthful stages of later forms; in fact he could often furnish just as exact a description of the form as if he had the adult genus before him.

NOMENCLATURE OF STAGES OF GROWTH.

In order to correlate ontogenetic stages with the generic changes seen in the development of the race it is necessary to have an exact scientific nomenclature. The most satisfactory is that given by Professor Hyatt in "Phylogeny of an Acquired Characteristic."[1]

TABLE OF ONTOGENETIC STAGES.

Stages	Stages	Substages	Comparison with phylogeny	
Embryonic	(1) Embryonic	Protembryo Mesembryo Metembryo Neoembryo Typembryo Phylembryo	Phylembryonic	Epacme
Larval	(2) Nepionic	Ananepionic Metanepionic Paranepionic	Phylonepionic	
Adolescent	(3) Neanic	Ananeanic Metaneanic Paraneanic	Phyloneanic	
Adult	(4) Ephebic	Anephebic Metephebic Parephebic	Phylephebic	Acme
Senile	(5) Gerontic	Anagerontic Metagerontic Paragerontic	Phylogerontic	Parac-me

With the embryonic stage the palæontologist can do nothing, except the very last substage or phylembryo, when the *Mollusca*, *Brachiopoda* and other groups begin to secrete their shells; but all the later stages are easily accessible in well-preserved material.

[1] Proc. Am. Phil. Soc., Vol. XXXII, No. 143, pp. 391 and 397.

The best example of correlation of ontogenetic stages with phylogeny is the genealogy of *Medlicottia*, worked out by Karpinsky,[1] who has shown that the Carboniferous genus *Pronorites* goes through the following stages: latisellate protoconch, phylembryonic; with the second suture it reaches the *Anarcestes* stage, nepionic; about the end of the first revolution the *Ibergiceras* stage begins, paranepionic; second revolution shows the *Paraprolecanites* stage, neanic; on the third whorl begins the *Pronorites* stage, adult. Thus with regard to *Pronorites* the genus *Anarcestes* is phylonepionic, *Ibergiceras* is phyloparanepionic, *Paraprolecanites* is phyloneanic. In the same work Karpinsky has shown that *Medlicottia* is a direct descendant of *Pronorites* and in its development goes through all the stages of the ancestral genus and adds several more. The first revolution of *Medlicottia* could not be studied, but on the second revolution was seen the *Ibergiceras* stage, metanepionic; on the third whorl the *Paraprolecanites* stage, paranepionic; at the end of the third whorl the *Pronorites* stage, beginning of the neanic; on the fourth whorl the *Sicanites* stage, end of the neanic: on the the fifth whorl the *Promedlicottia* stage, anephebic; and lastly, at end of the fifth whorl, *Medlicottia*, adult in characteristics, though not yet in size.

PALÆONTOGENY.

Groups available.—Vertebrates are out of the question for this sort of work, being too highly accelerated in their development; the stages that might be useful in phylogeny are gone through before the animal is capable of being preserved as a fossil. In the *Cœlenterata* the relations between Cenozoic and Palæozoic forms are not understood, and the ontogeny of available forms does not show stages that are striking enough to tell much. In *Echinodermata* difficulty of preservation of fossil forms makes ontogenetic study almost impossible, and recent forms have been too little studied for any comparison of stages of growth with ancient genera to be possible.

[1] Mém. Acad. Impér. Sci., St. Pétersbourg, VII Ser., Tome XXXVII, No. 2. "Ammoneen der Artinsk-Stufe."

The available groups are the *Brachiopoda*, the *Mollusca*, and the *Crustacea*.

Brachiopoda.—The brachiopods have this decided advantage, that they can be hatched in marine laboratories, and the various stages studied from the egg up, as has been done by Brooks, Kovalevski, Lacaze-Duthiers, Morse and Shipley, with the genera *Cistella*, *Glottidia*, *Lacazella*, *Liothyrina*, and *Terebratulina*. But it was reserved for the palæontologists Beecher, J. M. Clarke, and Schuchert to correlate the ontogeny of living forms with ancestral genera and give a biogenetic classification of the *Brachiopoda*[1] based on ontogenetic study.

In living specimens the subdivisions of the embryonic stage, protembryo, mesembryo, neoembryo, and typembryo may easily be made out, but since these are shell-less the work of the palæontologist begins with the phylembryonic substage, when the shell gland secretes the protegulum. From this upwards the palæontologist works on equal terms with the zoölogist, for the succeeding stages are capable of preservation, and may be compared with ancestral genera. Thus even the phylembryonic stage, or protegulum, is represented by the Cambrian genus *Paterina*, the ancestral prototype of all *Brachiopoda*.

Beecher and Schuchert[2] have also demonstrated that the *Ancylobranchia* (Terebratuloids) all go through a primitive Centronelliform stage, and that the *Helicopegmata* (spire-bearers) do the same and are for a while genuine *Ancylobranchia*. Schuchert's classification of the *Brachiopoda*, published in Eastman's translation of Zittel's *Text-Book of Palæontology*, 1896, may be taken as strictly biogenetic so far as the data now at hand make such a thing possible. And this is the only group of which we have a biogenetic classification.

[1] For correlation of stages of growth with generic changes, and for the literature on ontogeny and phylogeny of *Brachiopoda*, see papers by Dr. C. E. Beecher, Amer. Jour. Sci., Vol. XLIV, Aug. 1892, "Development of Brachiopoda," Part 2.; and Trans. Connecticut Acad. Sci., Vol. IX, March 1893, "Revision of the Families of Loop-bearing Brachiopoda;" and "The Development of Terebratalia Obsoleta Dall."

[2] Proc. Biol. Soc. Washington, Vol. VIII, July 13, 1893, "Development of the Brachial Supports in Dielasma and Zygospira."

Crustacea.—The only *Crustacea* that are useful for the study of palæontogeny are the trilobites, and since they are all extinct without leaving any descendants, modern biology can give us little help. We are thus to a greater extent than with the *Brachiopoda* thrown entirely on the ontogeny of fossils, and in this case, too, the various stages must be worked out from separate individuals. Many naturalists, beginning with Barrande, have worked on the ontogeny of trilobites, have described various stages, sometimes as larvæ, sometimes as adult genera or species, but they met with seemingly insuperable difficulties in correlating these stages with the genealogy. Dr. C. E. Beecher, however, has overcome these difficulties, presenting his results in a recent paper on "The Larval Stages of Trilobites,"[1] in which he shows that all trilobites go through a phylembryonic stage, protaspis, homologous to the protonauplius of the higher *Crustacea*. While no known genera are exactly like the protaspis, still there are several that retain many of its features. After the protaspis stage the various groups of genera develop in different directions, but all go through larval stages analogous to generic changes in their group. The protaspis itself of the later groups becomes more complicated by acceleration of development, but always retains its essential features. By means of this study Dr. Beecher has been able to give the beginning of a truly genetic classification of trilobites.[2]

Mollusca.—Of the *Mollusca* only the *Pelecypoda* and the *Cephalopoda* are of use to the student of palæontogeny, for the *Gastropoda* have not been classified in a satisfactory manner, and the larval stages even of living forms not well studied.

Pelecypoda.—Almost all that has been done in comparing genera of *Pelecypoda* with stages of growth is the work of Dr. R. T. Jackson,[3] who has shown that they all go through a phylembryonic stage, prodissoconch, analogous to the protegulum of

[1] Amer. Geol., Vol. XVI, Sept. 1895.

[2] Amer. Jour. Sci., Feb. and March 1897, "Outline of a Natural Classification of Trilobites."

[3] Mem. Boston Soc. Nat. History, Vol. IV, No. 8, 1890, "Phylogeny of the Pelecypoda."

Brachiopoda, the protoconch of *Cephalopoda* and *Gastropoda*, and the protaspis of trilobites. The prodissoconch is a straight-hinged, two-muscled, toothless, smooth-shelled, bivalve stage, corresponding to the primitive group of *Pelecypoda*. Even the monomyarian *Ostrea* goes through this dimyarian stage. Professor W. H. Dall[1] has used this and other facts in the development of the pelecypods, giving the most satisfactory classification up to this time. But from the very nature of the case, when the ontogeny of few living and no fossil forms is known, an evolutionary classification of pelecypods is impossible.

Cephalopoda.—The living dibranchiate cephalopods, *Octopus*, *Loligo*, *Spirula*, *Argonauta* and other common forms, are incapable of preserving the larval stages as fossils. The only living tetrabranchiate genus, *Nautilus*, can have its larval stages preserved as fossils, but is one of the old unspecialized types, not having changed greatly since the first nautilian shell, and consequently having no striking changes in its ontogeny.

The animals that are capable of giving the best proof of evolution are the ammonites. These branched off from the nautiloids at the beginning of the Devonian, continued increasing, diverging, became highly specialized and accelerated until their final extinction at end of the Cretaceous. Each ammonite goes through a larval history that is long and varied in direct proportion to the length of time from its period back to the Lower Devonian. Thus the *Nautilinidæ* are the first of the new stock, and their ontogeny is comparatively simple, there being no great changes from the larval up to the adult stages. The higher Devonian and Carboniferous forms go through several generic changes before they become adults, and the Mesozoic genera have still longer larval and adolescent periods, that is, longer in the sense of more complicated.

From the work of L. von Buch, Quenstedt, and others of the older palæontologists the increasing variety of forms from the goniatites of the Palæozoic to the ammonites of the Mesozoic

[1] Pelecypoda, Text-book of Palæontology, K. A. VON ZITTEL, Revised English Edition, Vol. I, Part I. Macmillan & Co., 1896.

was known long ago; these naturalists knew, too, that ammonites went through a goniatite stage of growth, without connecting this with evolution. By using their work we can get a comprehensive view of the development of ammonoids from the most primitive goniatites to the most highly developed ammonites, and thus construct a tentative family tree.

The simple primitive forms of the Lower Devonian branch out by the end of that age into two distinct stocks, the *Prolecanitidæ* and the *Goniatitidæ*, mostly low whorled, involute, with simple sutures and little ornamentation. Before the end of the Carboniferous some genera have already become ammonitic in the digitation of their sutures, as *Popanoceras*, *Thalassoceras*, *Pronorites*, and some have taken on ammonitic ornamentation of the shell, while the sutures remain simple and entire, as *Gastrioceras*. None of these forms, however, are very evolute, and the whorls are mostly rather low. In the Permian *Pronorites* and its descendants *Sicanites* and *Medlicottia* play an important part, *Arcestidæ* are already become important members of the fauna, the *Tropitidæ* are just beginning, while the *Glyphioceratidæ* are dying out. Some few genera still persist in the goniatitic stage, but most of them became ammonitic before the Trias was well on.

In the Trias the important groups are *Arcestidæ*, *Pinacoceratidæ*, *Tropitidæ*, *Ceratitidæ*, with numerous others less important as members of the Triassic fauna, but of great interest as ancestors of many of the chief families of the Jura and Cretaceous. In the Jura these ammonites reached their acme, branching out into very many families and subfamilies, increasing usually in complexity of sutures and variety of ornamentation. In the Cretaceous they gradually declined, dropping off one at a time until all were gone. The total number of *Ammonoidea* now described reaches about 5000, of which only a few hundred belong to the Palæozoic goniatites, the others belonging to the ammonites of the Carboniferous, Permian, and Mesozoic. Later than this no ammonoids are known.

Only simple radicles or stocks persist, but from time to time

certain genera branch off from the main stock, become highly specialized, and often give rise to so-called abnormal[1] forms, such as *Hamites*, *Baculites*, *Crioceras*, *Scaphites*, phylogerontic or degenerate genera, which do not perpetuate their race. These do not form a natural group, but are themselves even in some cases polyphyletic, as shown by their ontogeny; so far as examined their larval stages all correspond to various normal genera.

Of course there were phylogerontic genera that were not abnormal in shape; thus *Clymenia* branched off in the Upper Devonian into a variety of species, and disappeared as suddenly; *Medlicottia* reached its culmination in the Permian, barely managed to live on until the Trias, and disappeared without posterity, while the main stock of unspecialized *Prolecanitidæ* endured as long as the race. The number of phylogerontic forms increases in the Mesozoic, showing a constantly increasing tendency to become abnormal, until before the end of the Cretaceous the entire race of ammonoids becomes phylogerontic, and dies out from sheer lack of plasticity to modify itself further with changing conditions.

Such a general view or family tree of the ammonoids may be seen in any of the text-books of palæontology, especially those of Steinmann,[2] and of K. von Zittel,[3] where we get the best attempts to represent our present knowledge and ideas of the genetic relationships of ammonites. These genealogies are, however, purely tentative, based not on ontogeny but on comparison of series of adults. This would undoubtedly be the safest way if we had a perfect series of genera and species, but such a thing is unknown, and can never be obtained, on account of the incompleteness of the geologic record, and the mixing of faunas by migration in the past.

The researches of Hyatt, Branco, and Karpinsky have given us a surer way; from their work we have learned that the *Ammonoidea* preserve in each individual a complete record of

[1] J. F. POMPECKJ, Ueber Ammonoideen mit Anormaler Wohnkammer. Stuttgart, 1894.

[2] Elemente der Palæontologie. 1890. [3] Grundzüge der Palæontologie. 1895.

their larval and adolescent history, the protoconch and early chambers being enveloped and protected by later stages of the shell. And by breaking off the outer chambers the naturalist can in effect cause the shell to repeat its life history in inverse order, for each stage of growth represents some extinct ancestral genus. These genera appeared in the exact order of their minute imitations in the larval history of their descendants, and by a comparative study of larval stages with adult forms the naturalist finds the key to relationships, and is enabled to arrange genera in genetic series. They were all marine, never parasitic, and so with them there is no obscuring of the record; also in the *Mollusca* generic and specific characters show in the shell better than in the soft parts; so the classification of fossil ammonites is just as good as that of living shellfish.

Although genera appeared in the order of corresponding larval stages, they did not disappear in the same order; and so their survival under favorable conditions is liable to make confusion in the record, if one depends wholly on the study of series of adults. Such forms, for instance, as *Styrites*, *Tropiceltites*, *Miltites* and others that are now known only in the Karnic zone of the Upper Trias are undoubtedly such survivals, for they still have simple goniatitic sutures, very little ornamentation, and in general are more like Lower Triassic ammonites than members of the *Tropites subbullatus* fauna. The stray *Tirolites foliaceus*, which appears in the Alps and in California in this same fauna, is another survival of a Lower Triassic type, but fortunately we do know *Tirolites* in the horizon where it belongs. If this were not the case the naturalist would be very much puzzled at finding *Trachyceras* of the Karnic horizon going through a *Tirolites* stage in its early youth.

One great drawback to this work is that the ammonite faunas of the various ages have been classified by different specialists and on different principles, but all artificial. Thus the Triassic ammonites are divided into Leiostraca (smooth shelled), and Trachyostraca (rough shelled), a classification that cannot be extended even to Jurassic groups. The Trachyostraca are fur-

ther divided into *Tropitidæ*, with long body chamber, and *Ceratitidæ*, with short chamber. But neither of these groups is monophyletic, for it is quite probable, judging from their ontogeny, that members of both groups are derived from the *Goniatitidæ*, and others from the *Prolecanitidæ*. Further, the authorities agree in deriving the *Tropitidæ* from the *Glyphioceratidæ*, but the larval stages of some of the *Tropitidæ* show the undivided ventral lobe and an unmistakable resemblance to certain *Prolecanitidæ;* other so-called *Tropitidæ* show the divided ventral lobe at an early age, and a decided resemblance to the stock of *Glyphioceratidæ*.

In the same way most authorities agree that the Trachyostraca were all extinguished at end of the Trias, and that all the Jurassic and Cretaceous ammonites, with the exception of *Lytoceratidæ* and *Phylloceratidæ*, were derived from the radicle *Psiloceras*, and this, too, in spite of the fact that many of the genera are rough shelled, and in their larval stages show marked likeness to trachyostracan genera. Any naturalist can convince himself of this by looking at the young stages of Jurassic ammonites figured by Quenstedt.[1] Quite recently Professor W. Waagen[2] has called attention to the likeness of certain Trachyostraca to Jurassic genera, and indicated the probability of genetic relationships. But Mojsisovics[3] says that these similarities have nothing to do with relationship, but are purely "convergence phenomena," whatever that may mean. Resemblance of adults of Triassic and Jurassic forms might with some reason be ascribed to this mysterious agency, but surely no biologist would thus explain away the resemblance of larval and adolescent stages of Jurassic ammonites to adult Trachyostraca of the Trias. There was some excuse for such opinions as long as the fauna of the upper Trias was not well known, and there was apparently a great break in the series of ammonites. But after the appearance of the monographs of G. von Arthaber, Diener,

[1] Ammoniten des Schwäbischen Jura.

[2] Pal. Indica, Salt Range Fossils, Vol. II, p. 122.

[3] Das Gebirge um Hallstadt, Bd. II, p. 265.

Mojsisovics and Waagen,[1] on the Triassic faunas of the Alps, Himalayas, the Salt Range of India, and Siberia, there is no longer any such excuse. Ancestral types, long predicted by larval stages of Jurassic ammonites, may be seen in these works, as, for instance, *Tropiceltites*, which is exactly like the neanic stage of *Amaltheus;* but the great variety is confusing, and correlation difficult, on account of unsatisfactory classification.

The only solution of the problem is to classify genetically the Palæozoic goniatites, and from them work upwards into the Permian and Lower Triassic ammonites. These older groups have simpler larval stages, are not very greatly accelerated, and repeat clearly their ancestral history. When this is done the radicles will all be known, and when we know the stock of the tree, the branches that came off in the higher Trias, Jura, and Cretaceous will offer no difficulties. The most systematic attempt to do this is Haug's paper, "Les Ammonites du Permien et du Trias;"[2] but his classification is based wholly on the character of the sutures, and neglects other characters, such as sculpture and shape of the whorls. Thus Haug[3] places *Eutomoceras* with the prionidian family *Trachyceratidæ*, disregarding its ontogeny, which places it undoubtedly with the *Tropitidæ*. But no classification based entirely on one character can be truly genetic. Hyatt[4] in his monographs on the ontogeny of ammonites has shown us the way; Branco by his studies of the larval stages of ammonoids has accumulated a great mass of accurate data that can be used with confidence even by the student that rejects his theories as to classification. And Karpinsky, by using the methods and principles discovered by these naturalists, has worked out the genealogy of one of the chief stocks of the earlier ammonites.

[1] For the literature on Triassic faunas see JOUR. GEOL., Vol. IV, No. 4, J. P. SMITH, "Classification of Marine Trias."

[2] Bull. Soc. Géol. France, II Ser., Vol. XXII. 1894, No. 6.

[3] Op. cit., p. 408.

[4] Bull. Mus. Comp. Zoöl., Vol. III, No. 5, 1872; and Smithsonian Contrib. to Knowledge, "Genesis of the Arietidae," and other papers.

This way lies the truth, and not in groundless speculations such as many students of cephalopods are prone to indulge in.

Method of working.— In order to succeed, one must select material with great care, preferably limestone that is soft but not so weathered as to crumble, nor so brittle as to shatter. One's finger nail and some steel dental chisels are all the tools needed for breaking off the outer whorls of young ammonites. A microscope with thirty diameters magnifying power is the most satisfactory, although higher powers are occasionally needed. For studying surface markings a strong pocket lens is usually sufficient; the specimen should then be placed dry on white cardboard. For observing the sutures, or shape of the whorls, the specimen should be placed on cardboard in a drop of water, spread out so as not to distort the object. The water, being slightly viscous, will also hold the small object in any position. For taking measurements a micrometer eyepiece is needed, especially in drawing, for the *camera lucida* is not very satisfactory for drawing opaque objects. Sections can easily be cut by grinding with emery powder on a glass plate.

The accompanying illustrations will give an idea of how the facts are ascertained. A number of well-preserved adults of a species are selected, and the outer coils are pulled off piece at a time under water, until a complete series is obtained, representing every change in growth. All the pieces of whorls are preserved, but often it is possible to have a complete series in one specimen. The individuals representing stages of growth are kept separate, in small glass tubes attached to cards for labels, on which are noted the measurements of the specimen, stage of growth, and such other facts as are wanted for ready reference.

On plate *A* are shown the results of some work of this character. The species selected was *Schloenbachia* aff. *chicoensis* Trask, from the upper Horsetown beds, top of Lower Cretaceous, from Phœnix, Oregon. Fig. 1 shows the protoconch with part of the first whorl drawn as if unrolled. The protoconch is phylembryonic, representing the primitive ammonoid; the first suture, angustisellate, with narrow lateral lobes and saddles, is

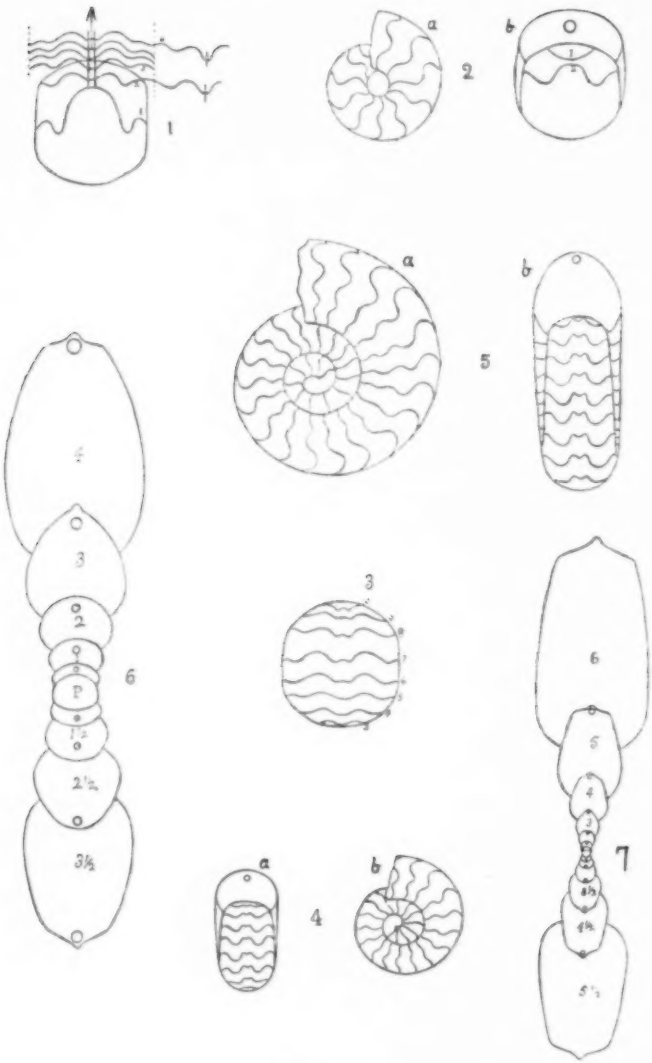

PLATE A.

ananepionic; the second suture with the abdominal lobe is metanepionic, and represents the ammonoid radicle *Anarcestes;* the third and fourth sutures correspond to *Tornoceras* and *Prionoceras;* the fifth suture is a transition from *Prionoceras* to *Glyphioceras;* and the sixth with the divided ventral lobe represents *Glyphioceras.*

Fig. 2 shows the larval stage, at diameter of $0^{mm}.68$, three-fourths of the first whorl. It has a low broad involute whorl, with divided ventral lobe, one lateral lobe, and another on the umbilical border. This stage is paranepionic, and is like the older species of *Glyphioceras.*

Fig. 3 shows the development of the sutures from the third to the tenth, on a specimen of diameter $0^{mm}.64$.

Fig. 4 shows the advanced *Glyphioceras* stage, with lobes and saddles, well developed, at diameter of $1^{mm}.20$; the second lateral lobe already begins to show on the umbilical shoulder. This stage is transitional to *Gastrioceras.*

Fig. 5 shows the end of the paranepionic stage, corresponding to *Paralegoceras*, at $2^{mm}.25$ diameter; the umbilicus widens, the whorls become higher and narrower, and a third lateral lobe appears on the umbilical border. The sutures still remain goniatitic, but in the next stage, ananeanic, ammonitic ornamentation, in the shape of a keel, appears at $2^{mm}.70$; and at $3^{mm}.20$ diameter the first lateral saddle becomes indented, and the adolescent stage is well along.

Fig. 6 shows a cross section through the center, diameter $6^{mm}.25$, four whorls, paraneanic. The inner whorls are low and broad, and the later ones become successively higher and narrower in proportion.

Fig. 7 shows a section through the protoconch, diameter $22^{mm}.25$, six whorls, adult stage; the relative increase of height of the whorls and the squaring of the abdominal shoulder is quite marked as the adult stage advances.

On these figures may be seen increase in number of lobes and saddles, change in position of the siphon from median to external, and the development of the whorls, in height, width, and involution.

By following this method on suitable material the complete ontogeny of any species may be worked out. In order to work out the phylogeny of any form it is necessary to combine this with comparative study of antecedent genera and species. When this is done for all the *Ammonoidea*, their genealogy will be more perfectly known than any other family tree possibly can be.

PLATE *A*.

FIG. 1. Protoconch of *Schloenbachia*, showing the first six sutures of the attached coil. Enlarged thirty times.

FIG. 2. Larval stage of *Schloenbachia*, diameter $0^{mm}.68$; thirty times enlarged; three-fourths of first whorl. 2*a*, side view; 2*b*, front view.

FIG. 3. Larval stage of *Schloenbachia*, diameter $0^{mm}.64$; thirty times enlarged. Showing sutures from the third to the tenth. From above.

FIG. 4. Larval stage of *Schloenbachia*, diameter $1^{mm}.20$; fifteen times enlarged. One and a half whorls. 4*a*, front view; 4*b*, side view.

FIG. 5. End of larval stage of *Schloenbachia*, diameter $2^{mm}.25$; fifteen times enlarged. *Paralegoceras* stage. 5*a*, side view; 5*b*, front view.

FIG. 6. Cross section of *Schloenbachia*, diameter $6^{mm}.25$; fifteen times enlarged; four whorls. Adolescent stage. The protoconch is seen in the center *P*.

FIG. 7. Cross section of *Schloenbachia*, $22^{mm}.25$; three and a half times enlarged; six whorls. Adult stage.

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EDITORIAL.

THE press announce the auspicious starting of Andrée on July 11. The result of this first experiment in Arctic aërial navigation will be awaited with unusual interest. If Andrée shall succeed in floating at a suitable elevation for even a week and shall make good his return, he can scarcely fail to bring back data of vital importance. It is of trivial consequence whether he passes near the pole or not, and his geographical discoveries are uncertain, for his course may not take him over new territory, but he will determine the course pursued by the body of air in which he floats if he is able to keep his location, of which there is little ground for question. The course pursued by a given body of air in a region which bears such critical relations to the whole system of atmospheric circulation is a matter of radical importance. Observers at fixed points upon the earth can only determine the transient local direction of passing bodies of air. They cannot directly demonstrate the actual circulation. They can only infer it from a combination of local observations. But the actual circulation can be determined by means of the balloon floating with the body of air, subject, of course, to certain obvious qualifications, particularly those that relate to vertical movements. Andrée's trip should therefore bring forth data of vital consequence to all hypotheses relating to polar atmospheric circulation. Among these hypotheses is one suggested by the ice drift which the writer has never seen in print, and which pointedly illustrates the possible value of Andrée's experiment.

It is now well known that the free ice off the Siberian coast drifts westward until it impinges upon the east coast of Greenland, when it is diverted to the south, but on reaching Cape

Farewell it rounds to the westward and even northward, until it is again arrested by Baffin Land and the American mainland, and forced southward. The marvelous trip of Nansen has given this a heroic demonstration not likely to be questioned. It is also known that the ice fields north of Greenland and Grinnell Land press hard against the coast, and crowd through the straits between these lands in a southwesterly direction. It is also known that the ice presses hard on the north side of the Parry Islands and pushes southward and eastward, effectually blocking all the straits between them as well as Jones Sound on the east. It is also known that Banks strait and McClintock channel, trending from the northwest to the southeast, are effectually blocked by the persistent jam of the ice crowding in *from the northwest*. It is the strong and unremitting jam of ice into this channel that has rendered all attempts at the northwest passage abortive. Correlating these movements, it appears that there is a common drift towards some point not far distant from the magnetic pole.

Now it is well recognized that this ice drift is essentially controlled by the winds. The sea currents are, to be sure, a factor, but, except as they are an expression of wind action, they seem to be relatively ineffectual. These movements have therefore suggested the hypothesis that the pole of the winds is not identical with the pole of the earth, but lies somewhere in the quarter toward which the ice drift tends to concentrate itself. This is based on the assumption that the supposed spiral course of the winds about the atmospheric pole tends to concentrate the ice at it. It is not difficult to find data in lower latitudes that fall in with this hypothesis, as, for instance, the predominant course of mid-latitude cyclones in this country and the trend of the Asiatic arid belts.

This is not the place to argue the hypothesis nor to set forth the numerous and important corollaries that spring from it. A sufficient number of significant corollaries will doubtless suggest themselves to indicate its importance, *if true*. The purpose in hand is to show how decisive the determination of the course

of any representative body of air in those regions must be on such a hypothesis and on similar hypotheses. If Andrée's balloon follows a spiral course (cyclonic gyrations aside) whose center lies in the quarter toward which the ice concentrates, the hypothesis will receive encouragement. If not, it becomes a hopeful candidate for the limbo of unsupported inferences. The reverse may be said respecting the common assumption of a strictly axial whirl, but as that rests on general probabilities it does not so well illustrate the critical value of an actual test of the movement of the air.

On quite other grounds it might equally well be affirmed that the navigation of the Arctic air by balloons will, if found practicable, have its own peculiar function which neither ship nor sledge can supply. T. C. C.

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THE state of Missouri has recently had deep disgrace thrust upon it by the removal of the efficient director of the Geological Survey and by the appointment of men to its care and conduct who possess, according to information that we deem trustworthy, not only no competency to perform their duties, but not even a plausible semblance of competency. These appointments have apparently no other motive than the conferring of personal or political favors. No causes of complaint, we are informed, were even alleged against the previous conduct of the Survey or against the officials in charge of it. The scientific public has had ample demonstration of the vigor and energy with which the Survey has been prosecuted, the promptness with which its results have been published, and the adaptation of the work to the development of the economic as well as scientific resources of the state. It appears, therefore, that the moneys appropriated by the state of Missouri for the laudable purpose of investigating and advertising its resources and of informing its people concerning their own sources of material and intellectual wealth are being virtually diverted from the purposes specifically indicated by the statute of the state, and are being used for the personal and political interests of the

governor and his friends in the form of payment for worthless services. We are not sufficiently informed in the technicalities of law and the processes of the courts to know how legal action in a case of this kind can be instituted and maintained, but if the appointees are as obviously incompetent as information indicates, they are simply consuming the funds of the state to no purpose save their own, and we think that an effort should be made to procure a formal declaration by the courts whether this is not a virtual embezzlement, and if so, to secure the award of the proper punishment. If there is now no way of compelling a governor to respect the laws of a state and the purposes of its statutes, a way should be provided. T. C. C.

Reviews.

The Bedford Oölitic Limestone of Indiana. By T. C. Hopkins and C. E. Siebenthal. Extr. 21st Ann. Rep. Dept. of Geology and Natural Resources (of Indiana). W. S. Blatchley, State Geologist, Indianapolis, 1896.

All of the older geological maps of Indiana show the various rocks across that state in broad, sweeping lines, and that, too, in spite of the fact that the rocks are everywhere nearly horizontal and have been deeply trenched by the streams. The last two reports of State Geologist Blatchley have shown a great improvement in this respect — the maps by Hopkins and by Kindle in the twentieth report and those by Hopkins and Siebenthal in the twenty-first report are by far the best that have yet appeared of the areas represented, showing, as they do, the dendritic form of outcrop to be expected.

From the earliest to the latest of the Indiana reports, almost every one has had something to say of the well-known oölitic limestone; but hitherto there has been no report on this rock that could lay claim to being a systematic description and discussion of it. The present report bears internal evidence of having been prepared under pressure, but it is nevertheless a highly creditable and valuable piece of work, and by far the best report ever made on the Bedford stone. The maps show a vast amount of field work, and exhibit for the first time the distribution of this valuable building stone. We are glad to see that the authors do not feel it incumbent upon themselves to "puff" the Bedford stone. This and every other good building stone, once it is given a chance, may be trusted to take care of its own reputation without any such help from geologists as that quoted on page 323. Evidently some people think the truth can be improved upon. What Mr. Hopkins says is certainly as much as reasonable people can ask. "The Bedford oölitic limestone can unhesitatingly be recommended as one of the most durable building stones on the market, where not exposed to the action of acids. It is fireproof up to the point of cal-

cination, in which property it can be surpassed by no other limestone and but few other building stones, as very few are absolutely fireproof." The list of the more important buildings made of the oölitic limestone at the end of the report shows that it is already used in almost every state of the Union, in which use the cities of Chicago, Indianapolis, and New York lead.

Statistics show that over six million cubic feet of Bedford stone was quarried in 1895, worth more than a million and a half of dollars; 1784 men were employed that year in the quarries, to say nothing of those engaged in stone-cutting, transportation, and building. The work includes valuable statistics, tests, and analyses, and many instructive photographs of quarries, machinery, exposures, and buildings, and closes with a bibliography of oölites in general and of the Bedford stone in particular.

In the way of minor criticisms abandoned quarries are indicated on the maps, but not those in operation; while the lithographing of the maps is neatly done, the distinctions between formations might have been clearer in some cases without increasing the cost of the maps.

The most serious criticism of the report is one for which the authors are not responsible, but it is one that unfortunately applies to many of our state reports, and is referred to here rather on general principles than on account of it being especially applicable to the present case; we refer to the short time allowed for its preparation. No matter what the worker's aims, intentions, or abilities may be, behind him is the state geologist demanding much work in a short time and at little expense; the state geologist imagines the legislature is making the same demands on himself, while behind the legislature are the people asking for practical results. In our national surveys we have pretty much the same state of affairs—a constant demand for something to show for the money used. As a matter of fact, the practical results of hasty work cannot be the best results. Haste in work of this kind, like haste in other things, is waste. It is our decided opinion that no member of a legislature or of Congress will object to allowing a state or a national geologist time to do good work if only the truth is placed fairly before him. Last year we had a valuable paper by Professor Hopkins on the carboniferous sandstones of Western Indiana; this year we have the present report on the Bedford stone, and some other year we shall have reports on other building materials of Indiana. Thus the matter that ought to have formed a single mono-

graph is scattered through several volumes, disconnected, and therefore less known and less valuable either to the state or to the general public. Nevertheless, the state geologist is to be congratulated on his selection of men to do this work and on the results obtained in so short a time, for it is unquestionably one of the very best reports made in this country upon building stones. J. C. BRANNER.

The Ancient Volcanoes of Great Britain. By SIR ARCHIBALD GEIKIE, F. R. S. Macmillan & Co., London and New York, 1897.

This work, as Sir Archibald Geike states in the introduction, is the outgrowth of his presidential addresses before the Geological Society of London in which he sketched the volcanic action in ancient times in Great Britain, whose record is left in the igneous rocks of several epochs from pre-Cambrian to Tertiary. No other part of the earth, so far as now known, presents within a comparatively small area such evidences of oft repeated volcanic action through so great a period of time. Commencing in pre-Cambrian times with three definitely localized volcanoes, the series is found to have extended through the Cambrian, Silurian, Devonian, Carboniferous, Permian and Tertiary times. The importance of the evidence furnished by so extensive a series of periods of volcanic activity as to the cause of volcanic action, and the source of the materials erupted must be apparent.

Its bearing on the question as to whether volcanic phenomena differed materially in the earlier periods of geological history from those of recent date, is also most valuable. And it is to be noted that the conclusion reached is that they are alike. The presentation of the facts known about these ancient volcanoes involves a description of rocks that were formed in various situations in the volcanoes; upon their surface, within their mass or within rocks beneath or about them; and which were subjected during the ages to processes that have modified their internal character and sometimes their external form. In order that these descriptions may be understood by the general reader the first chapters of the work are devoted to a consideration of general principles and methods of investigation. The nature and causes of volcanic action, and the phenomena connected with modern volcanoes are briefly noted. Considerable space is given to the characteristics of

ancient volcanoes, the nature of the material erupted, and the several types of volcanoes. Underground phases of volcanic action are also described; and the effects of subsequent denudation in exposing the rocks and their influence on the topography and scenery are discussed.

The major part of the work treats in detail of the volcanic phenomena connected with each period of activity, beginning with that in the pre-Cambrian time. Upon petrographical grounds the most ancient Lewisian gneiss, corresponding to what is often called Archæan, is considered to have been originally a mass of various eruptive rocks. Although they have been subjected to great mechanical deformation, the present banded structures are connected with the original igneous condition of the rocks. They were probably underground lavas, possibly connected with extrusive bodies. With these rocks are associated dikes of basic and acid rocks. Rocks of volcanic origin undoubtedly occur in the Dalradian schists of Scotland and in the gneisses and schists of Anglesey. The Uriconian, Malvern, and Charnwood Forest volcanic rocks are all of pre-Cambrian age. The volcanoes of Cambrian time occurred in South Wales, North Wales, Malvern Hills, and Warwickshire; those of Silurian time occurred in Wales, North of England and in Scotland, and Ireland; partly in the Lower, partly in the Upper Silurian. Volcanic activity was pronounced in Middle Devonian times but in certain districts extended into the Upper Devonian. In the period of the Old Red Sandstone there existed numerous centers of volcanic activity. In Lower Old Red Sandstone time they extended from Shetland to the Chevoit Hills in England and even to Lake Killarney, and from the coast of Berwickshire on the North Sea to near Lough Erne in the north of Ireland. They are less numerous in Upper Old Red Sandstone time, occurring in the southwest of Ireland and the north of Scotland. The Carboniferous age was marked by prolonged volcanic activity in Scotland and by restricted activity in England and Ireland. The volcanoes were partly of the plateau, partly of the puy type, accompanied, of course, by intrusive bodies. The Permian volcanoes of Scotland and England are much less important.

Four fifths of the second volume are devoted to the volcanoes of Tertiary time, for the reason that they are the most recent and their rocks are the freshest and most abundant. They occur along the west coast of Scotland and the northeast of Ireland. The dikes, plateau, and fragmental rocks are described in detail, and an account of the mod-

ern volcanoes of Iceland is introduced by way of illustration. The eruptive vents and the intrusive bodies, as sills and bases, both basic and acid, are also described.

The work closes with an account of the subsidences and dislocations of the plateaux and the effect of denudations. The final chapter consists of a brief summary together with the following general deductions: The distribution of the centers of volcanic activity has been along the western side of the country in a north and south line. The persistency of volcanic activity in this region and its restriction to particular localities are some of its most marked features. The sites of volcanic vents in Britain do not seem to have been determined by any obvious structures in the rocks now visible. Volcanic phenomena cannot be regarded as mere isolated and incidental features in the physics of the globe. They are intimately connected with profound terrestrial movements. They have been essentially uniform since the beginnings of geological time. In extent and rigor the earliest eruptions of which we have records did not differ in any important respect from those of the present time. However volcanic energy has not manifested itself uniformly throughout geological time. There have been periods of maximum and of minimum effectiveness. The character of the volcanic rocks and the general sequence of their eruption have been the same with slight modification for all the periods of activity in this region.

J. P. IDDINGS.

The Submerged Valleys of the Coast of California, U. S. A., and of Lower California, Mexico. GEORGE DAVIDSON, A.M., PH.D., Sc.D. (Member of the National Academy of Sciences, etc)., Proc. Calif. Acad. Sci. Third Series, Geology, Vol. 1, No. 2. With Nine Plates. San Francisco, 1897.

This paper gives a brief description of the Pacific coast from the southern extremity of Lower California to the Strait of Fuca. The general character of the coast, south of Cape Mendocino, is bold and rocky, reaching considerable elevations within a few miles of the shore. These coastal ranges are broken by valleys and plains of varying width which may or may not correspond to the submarine depressions described.

Bordering the coast from about Cape Mendocino southward there is generally a submarine platform, having an average width of ten miles,

and extending to the 100-fathom curve. Beyond this platform the descent is usually rapid, 2000 fathoms being reached in from 35 to 100 miles from the shore.

In this 100-fathom platform the submarine valleys are found, heading either close to the shore or only a short distance out, and extending to a depth of from about 100 to at least 600 fathoms. These valleys vary largely in direction, form, and character of the bottom. Four valleys are found off the coast of Lower California and seventeen are described from the California coast. They are most numerous near the southern end of the state, and near Cape Mendocino, where four of considerable size are found within a stretch of twenty miles. These four are peculiar in heading under the highest parts of this strip of coast, while the majority of the channels are opposite valleys or openings in the coast ranges. All of the valleys are described in some detail and are well shown by submarine contours on the accompanying maps. North of Cape Mendocino no submarine valleys have been noted with the exception of one indicated near the mouth of the Columbia River.

Although this paper is of importance to geologists, no direct attempt is made in it to give the geological bearing of the facts stated. One assumption, which is open to criticism, is made by the author in using the term "submerged" where he formerly used "submarine," to describe these valleys, since it is doubtful whether all of them can be considered as submerged channels. The studies of the present writer on the submarine topography of a part of the California coast have led him to the conclusion that no general statement can be made as to the origin of these valleys. They may be due to one or more of three causes — either (1) they are structural, due to faulting or folding; or (2) they are due to the forces of subaërial erosion, and therefore are strictly "submerged valleys;" or (3) they may possibly be due to subaqueous erosion in delta deposits. Under which of these heads a given valley should be placed must be determined by a special study not only of the submarine features but of the topography, stratigraphy and structure of the neighboring land area, and possibly also of the characters of the shore-currents at that point.

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